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LLNL-CONF-423982

Precision Engineering within the National Ignition Campaign

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10th International Conference of the European Society for Precision Engineering & Nanotechnology
Delft, Netherlands
May 31, 2010 through June 4, 2010

Disclaimer

Precision Engineering within the National Ignition Campaign

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The 10th International Conference of the European Society for Precision Engineering and Nanotechnology
Delft, the Netherlands
June 1-3, 2010

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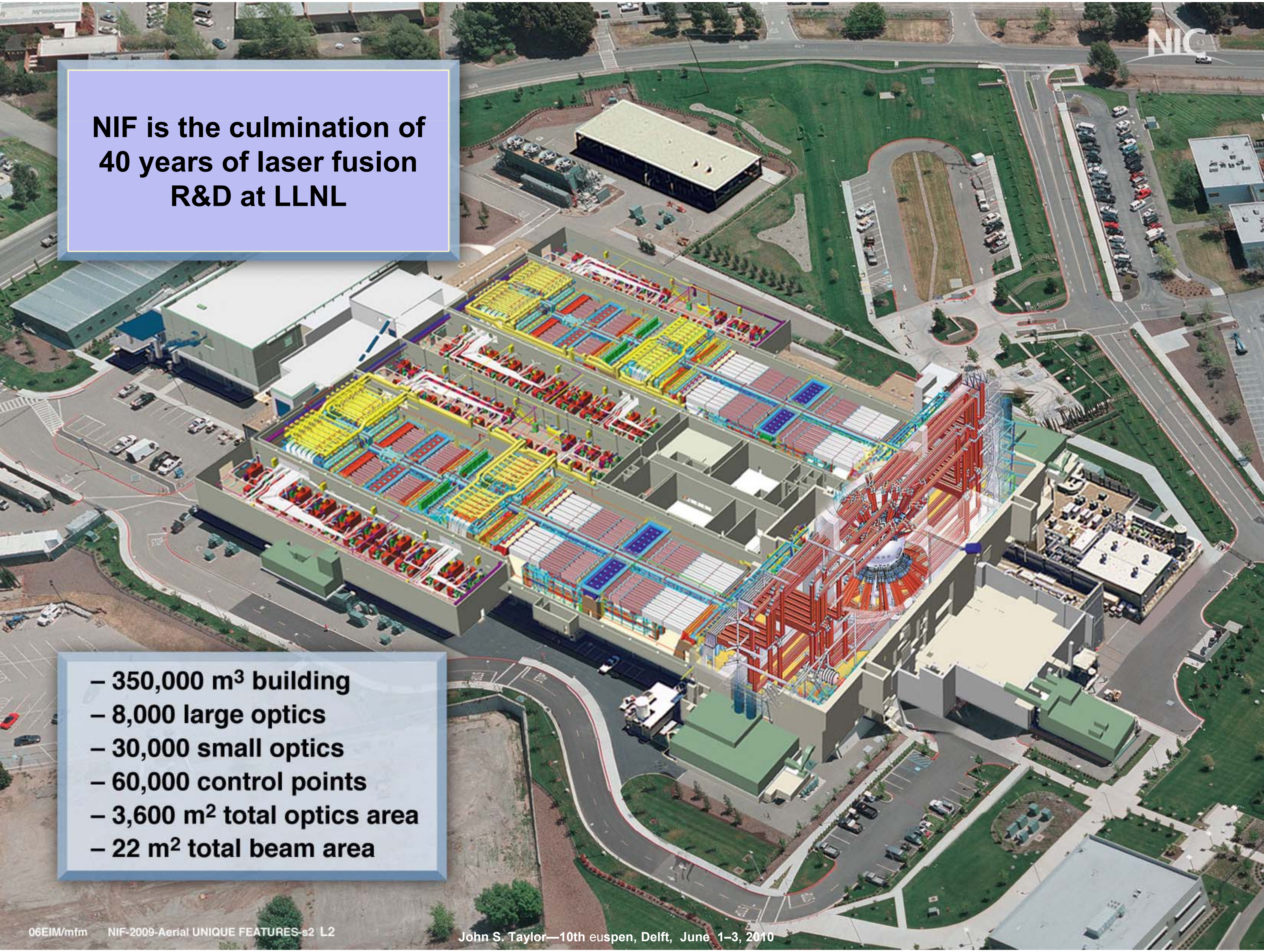
LLNL-CONF-433952


NIF
San Francisco
(45 mi.)
LLNL
National Ignition Facility

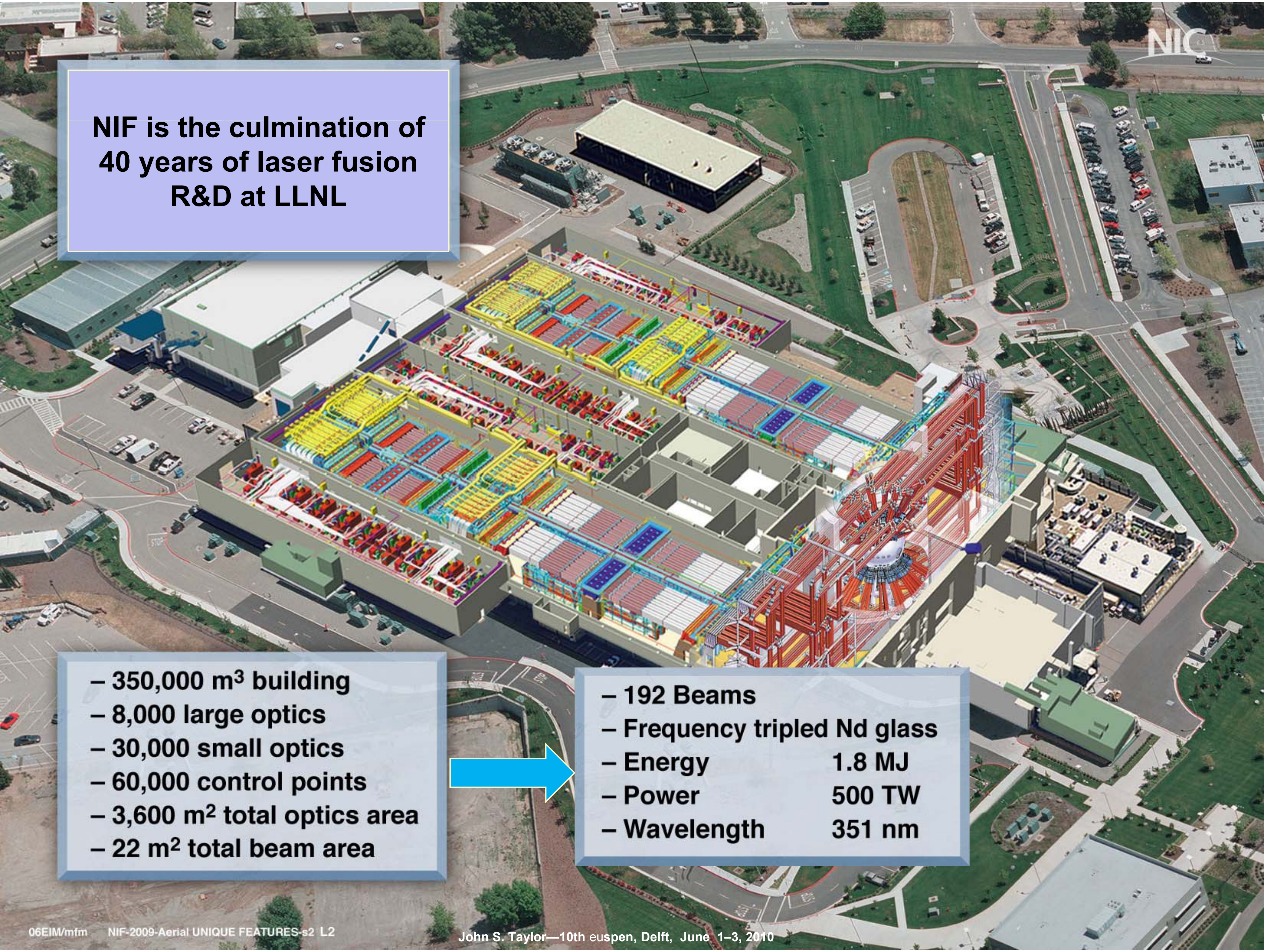
NIF concentrates all 192 laser beam energy in a football stadium-sized facility into a mm^3

Matter Temperature	$>10^8$ K
Radiation Temperature	$>3.5 \times 10^6$ K
Densities	$>10^3$ g/cm^3
Pressures	$>10^{11}$ atm

NIF is the culmination of 40 years of laser fusion R&D at LLNL

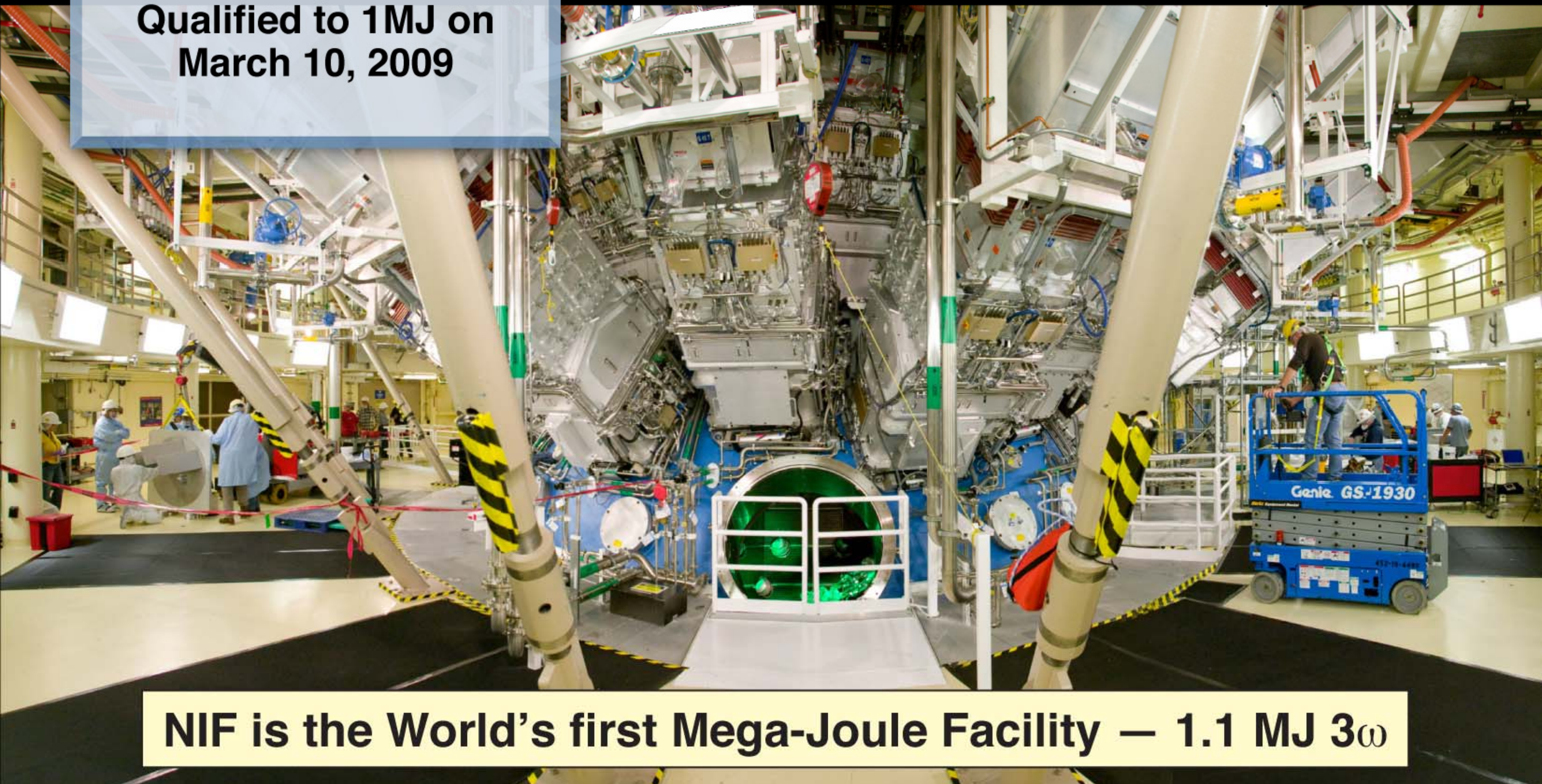


- 350,000 m^3 building
- 8,000 large optics
- 30,000 small optics
- 60,000 control points
- 3,600 m^2 total optics area
- 22 m^2 total beam area


NIC
NIF is the culmination of 40 years of laser fusion R&D at LLNL
– 350,000 m³ building
– 8,000 large optics
– 30,000 small optics
– 60,000 control points
– 3,600 m² total optics area
– 22 m² total beam area
– 192 Beams
– Frequency tripled Nd glass
– Energy 1.8 MJ
– Power 500 TW
– Wavelength 351 nm
STOP
06EIM/mfm NIF-2009-Aerial UNIQUE FEATURES-s2 L2
John S. Taylor—10th euspen, Delft, June 1–3, 2010

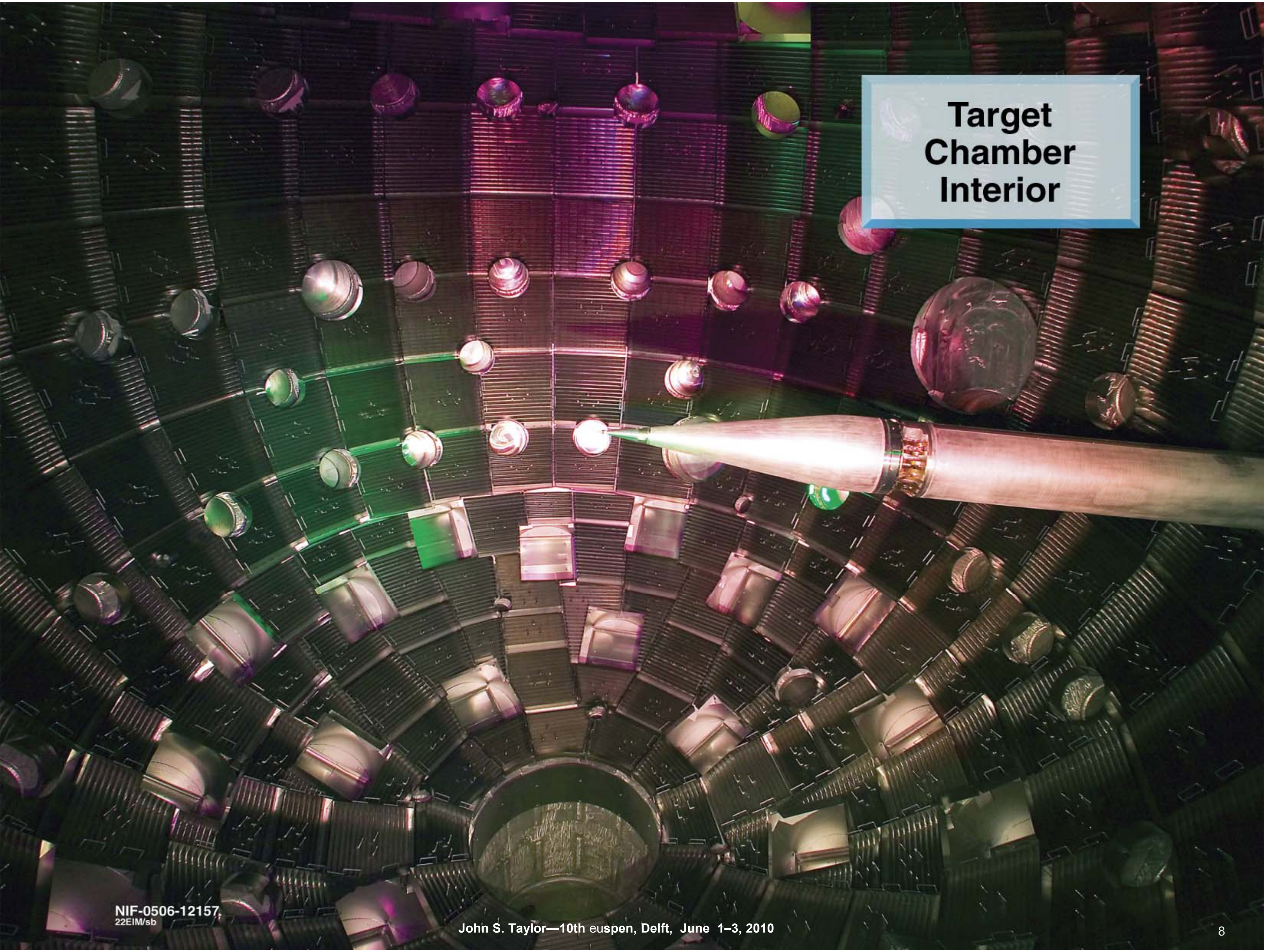
Target Chamber Dedication June 1999

NIF Laser Operationally Qualified to 1MJ on March 10, 2009



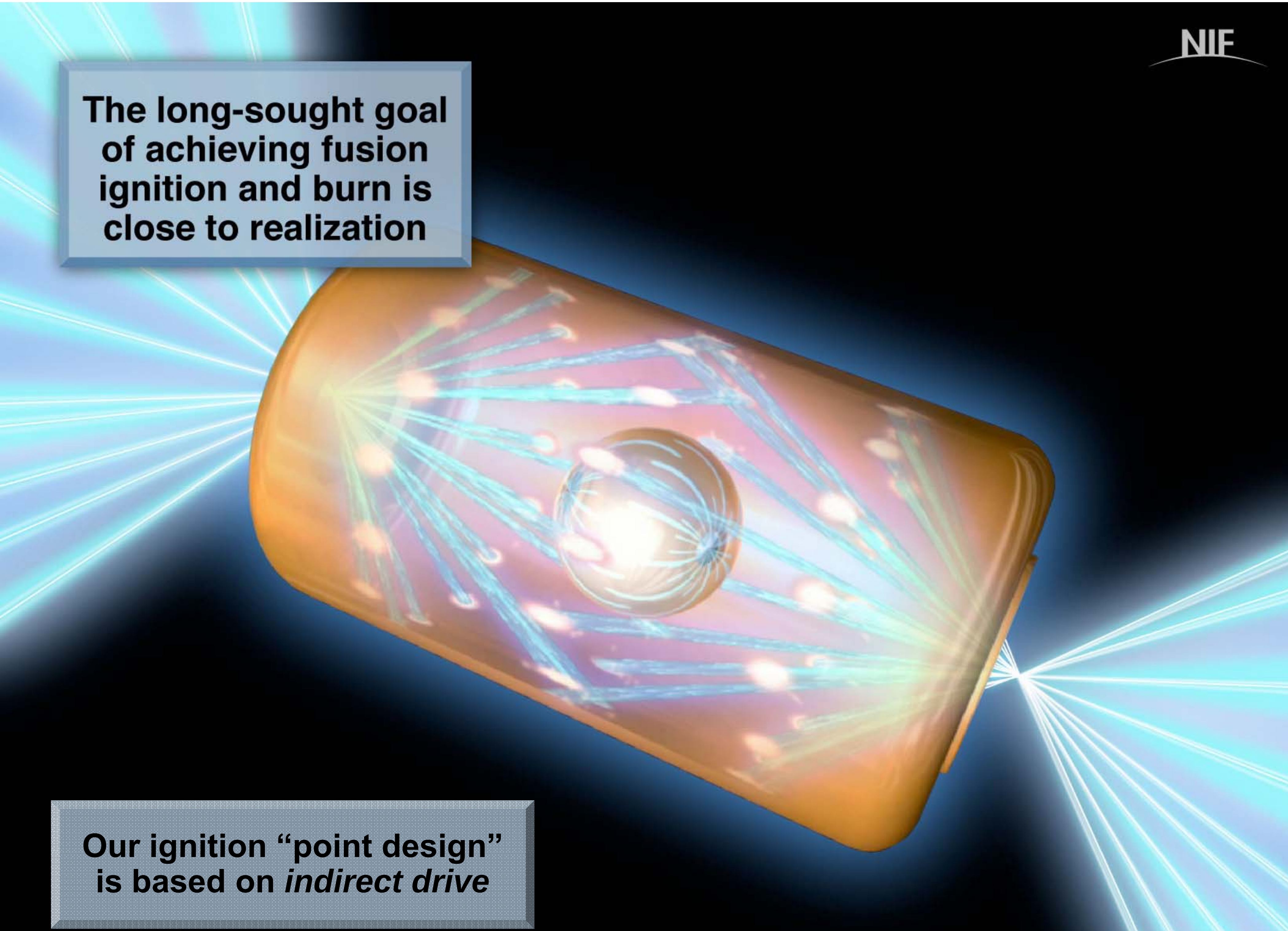
NIF is the World's first Mega-Joule Facility — 1.1 MJ 3ω

Cluster 4 | Cluster 3 | Cluster 2 | Cluster 1


Target
Chamber
Interior
NIF-0506-12157
22EIM/sb

NIF

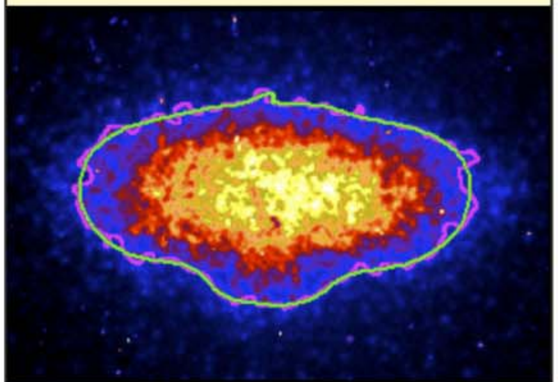
The long-sought goal of achieving fusion ignition and burn is close to realization



Our ignition "point design" is based on *indirect drive*

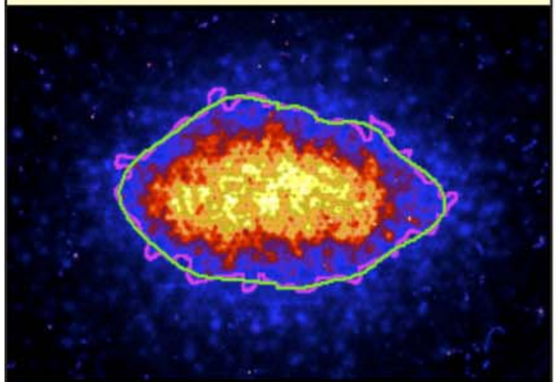
Capsule implosions in cryogenic gas-filled hohlraums have shown good symmetry at 270 eV

Wednesday, Sept. 2



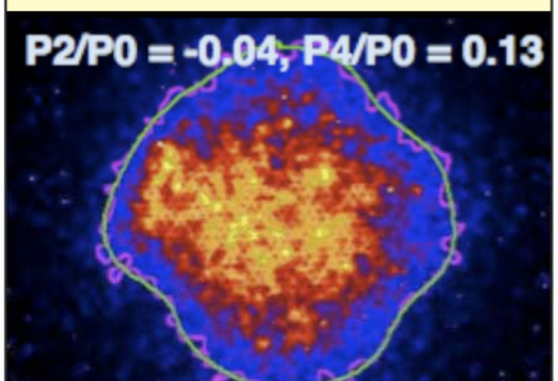
1st cryo implosion

Thursday, Sept. 3



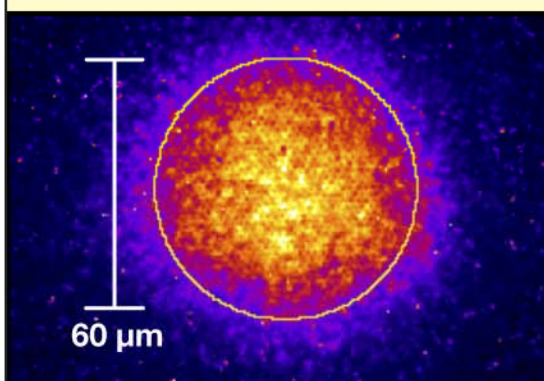
2nd cryo implosion

Friday, Sept. 4



3rd cryo implosion

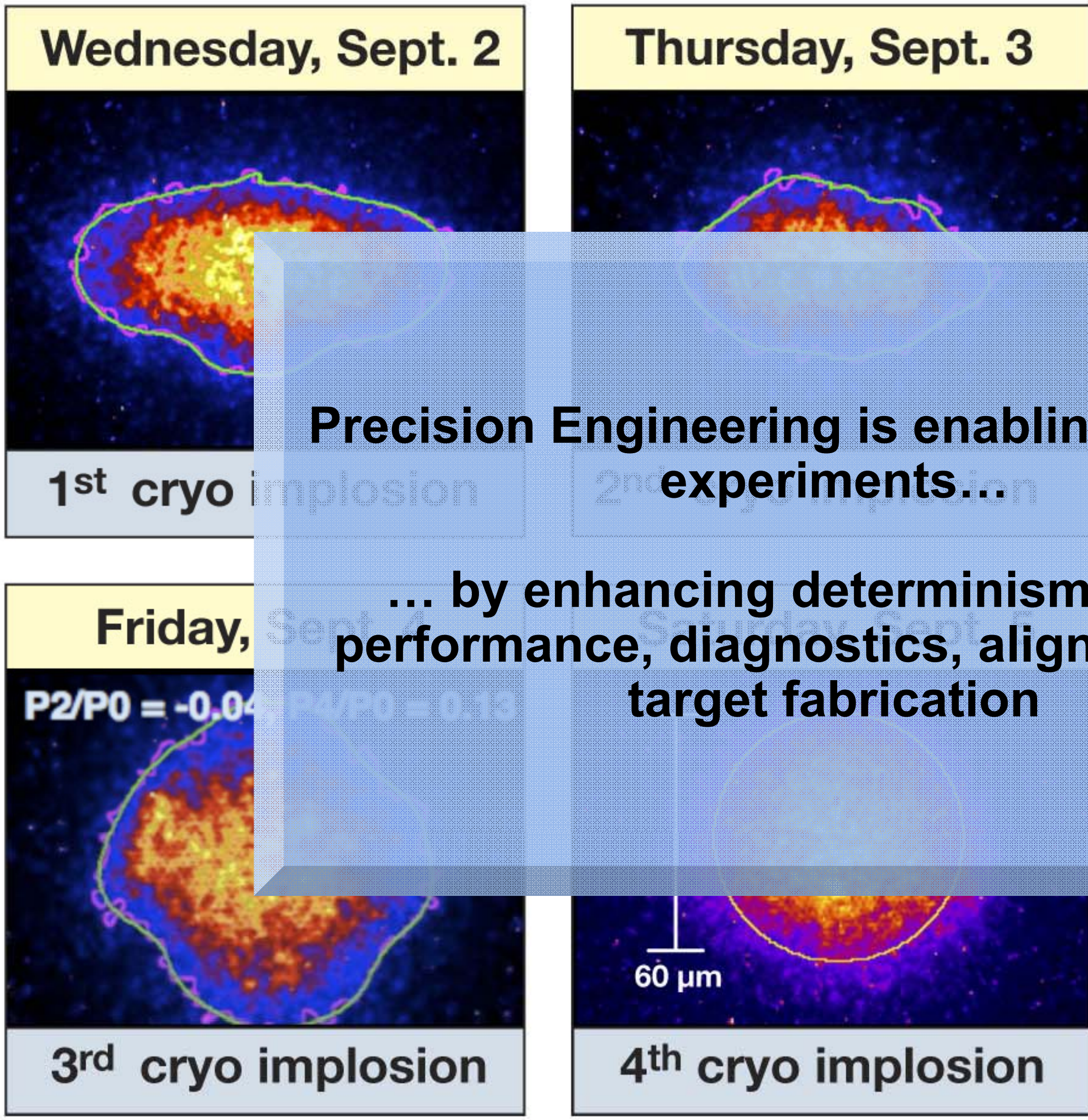
Saturday, Sept. 5



4th cryo implosion

- Initial capsule diameter: 1.8 mm
- Emitting region 33x smaller than capsule diameter
- Consistent with 10-15 mass compression
- Very symmetric implosion P2 ~7%

Capsule implosions in cryogenic gas-filled hohlraums have shown good symmetry at 270 eV



- Imaged capsule diameter: 1.8 mm
- Emitting region 33x smaller than capsule diameter
- Consistent with 10-15 mass compression
- Very symmetric implosion P2 ~7%

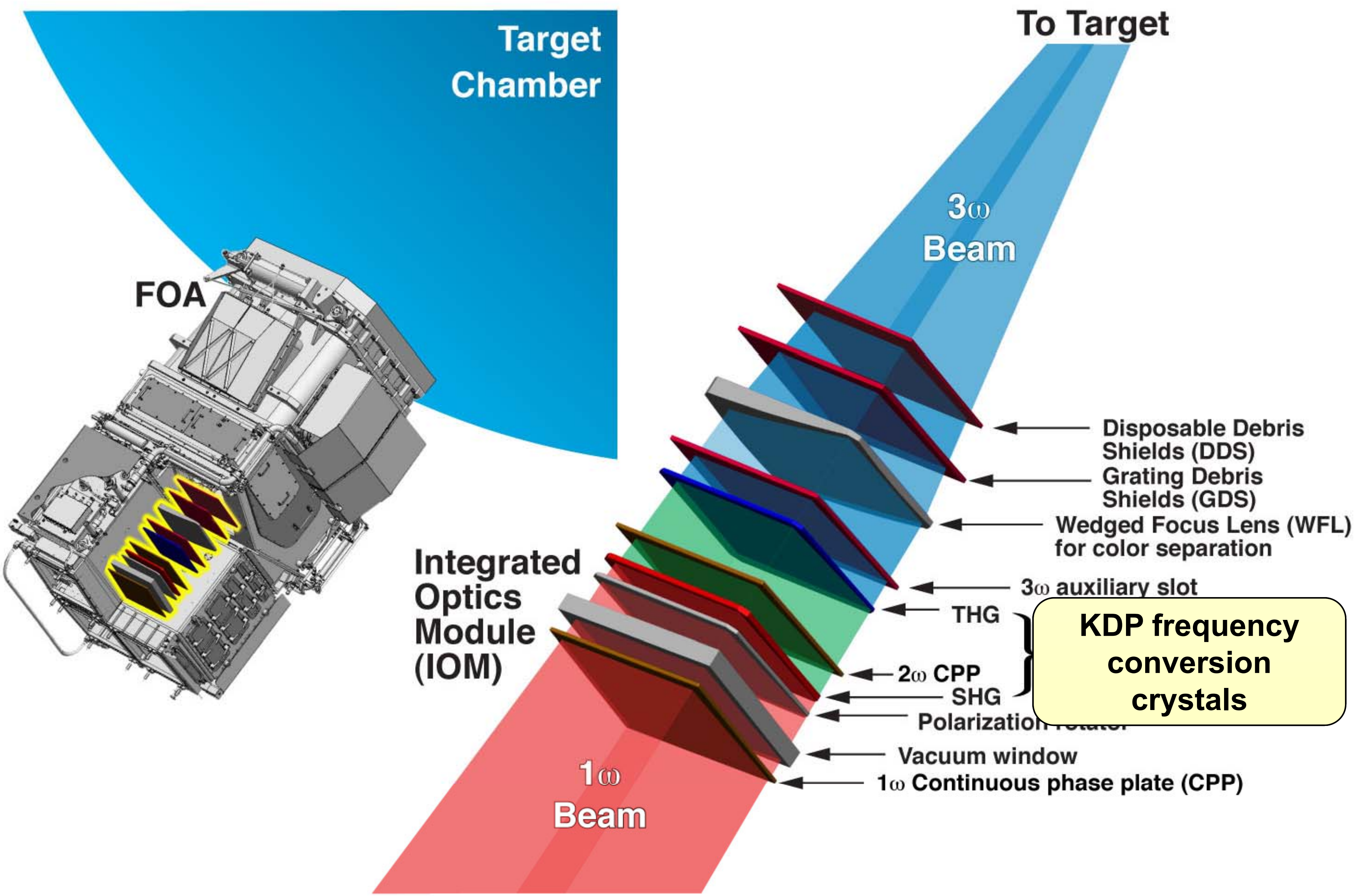
Precision Engineering is enabling landmark experiments…

… by enhancing determinism in laser performance, diagnostics, alignment, and target fabrication

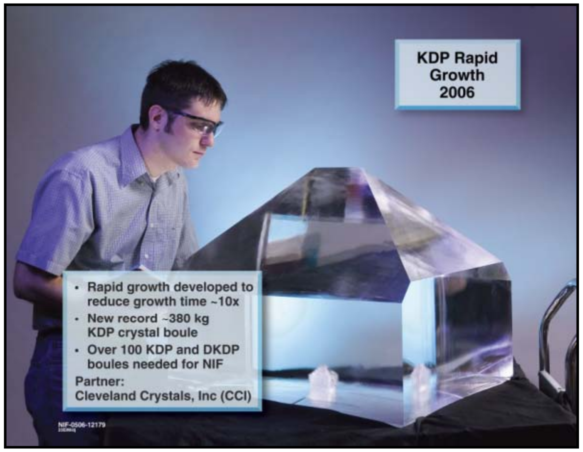
In this very brief talk, we'll discuss how precision engineering impacts 4 key areas of NIF

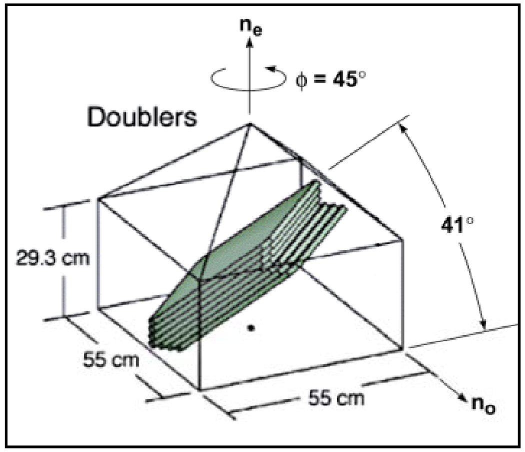
- Diamond turning of KDP crystals
- Mitigation of laser damage on optics
- Alignment of lasers, targets, diagnostics
- Target fabrication

The Final Optics Assembly (FOA) combines a number of critical functions into a single compact package



KDP Semi Finishing Machine – Vertical Axis Fly-cutter

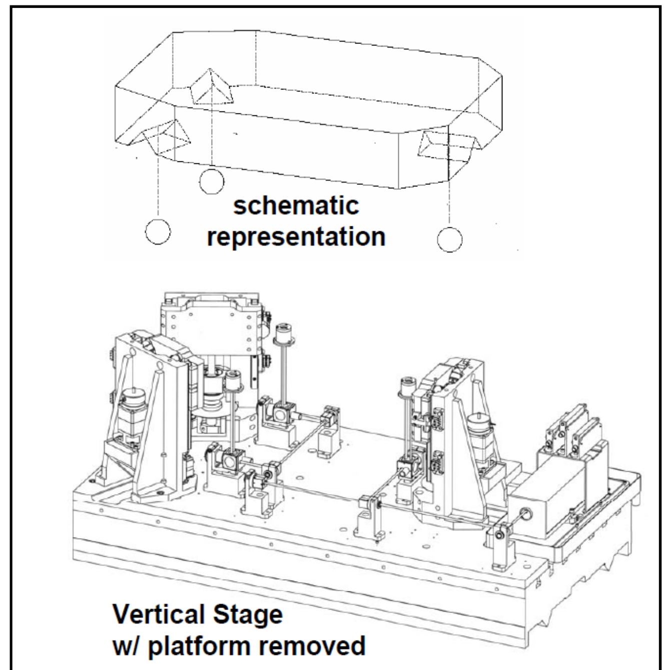




Diamond Fly-cutting to obtain the required crystal angle

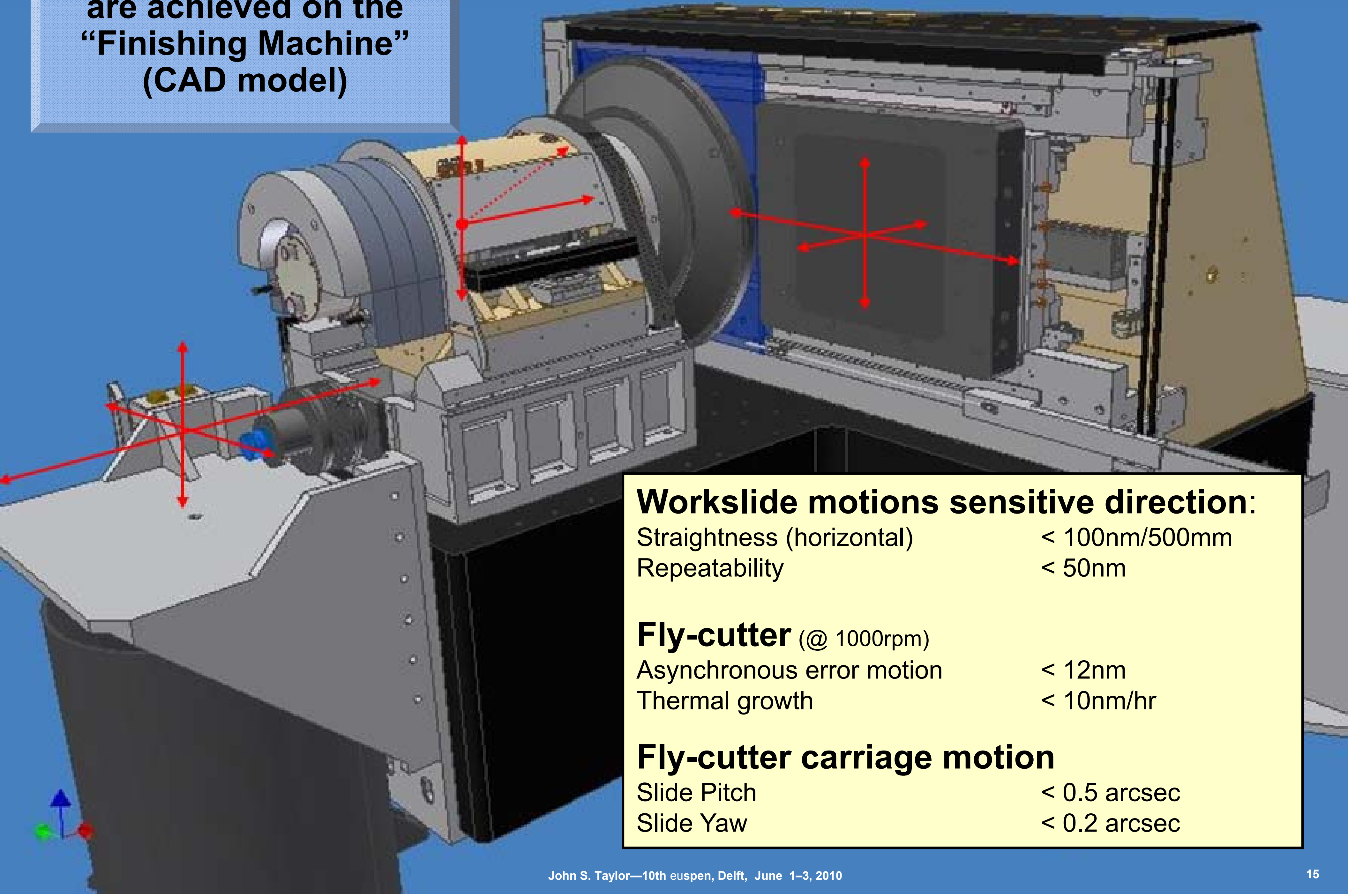
- KDP Optics are used for laser frequency conversion
- NIF operates by first doubling and then tripling
- Crystal growth axis determines frequency

KDP crystal in mounting fixture



Tip and tilt platform

Final figure and finish are achieved on the "Finishing Machine" (CAD model)



Workslide motions sensitive direction:

Straightness (horizontal)	< 100nm/500mm
Repeatability	< 50nm

Fly-cutter (@ 1000rpm)

Asynchronous error motion	< 12nm
Thermal growth	< 10nm/hr

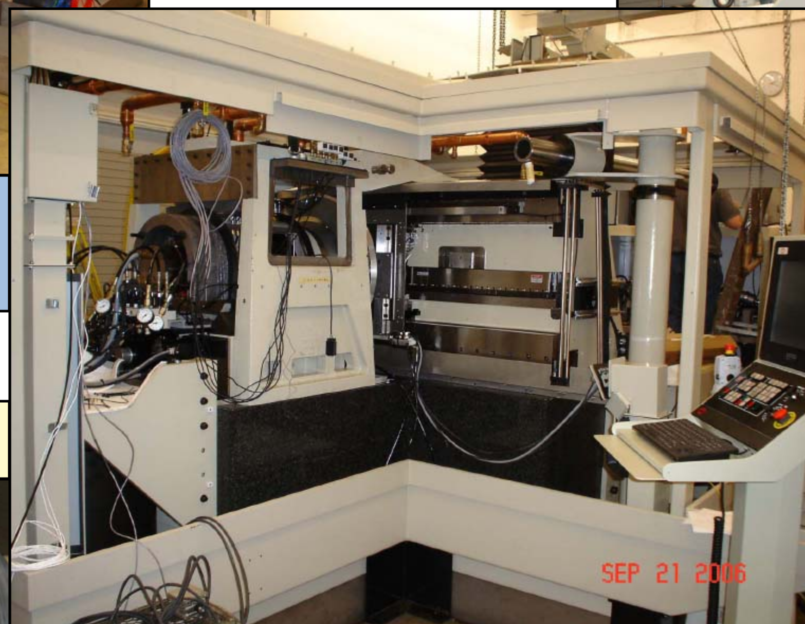
Fly-cutter carriage motion

Slide Pitch	< 0.5 arcsec
Slide Yaw	< 0.2 arcsec

KDP Finishing Machine during the build

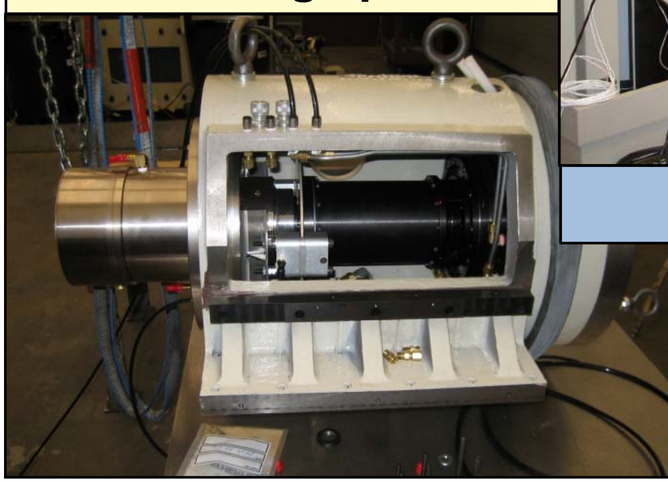
Granite base on air isolators

X-axis way installation

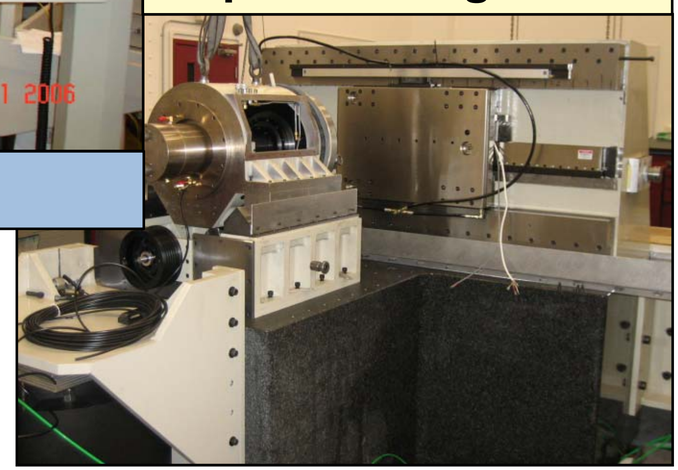


Completed system

Air bearing spindle



Spindle integration



KDP Finishing Machine installed at vendor's facility

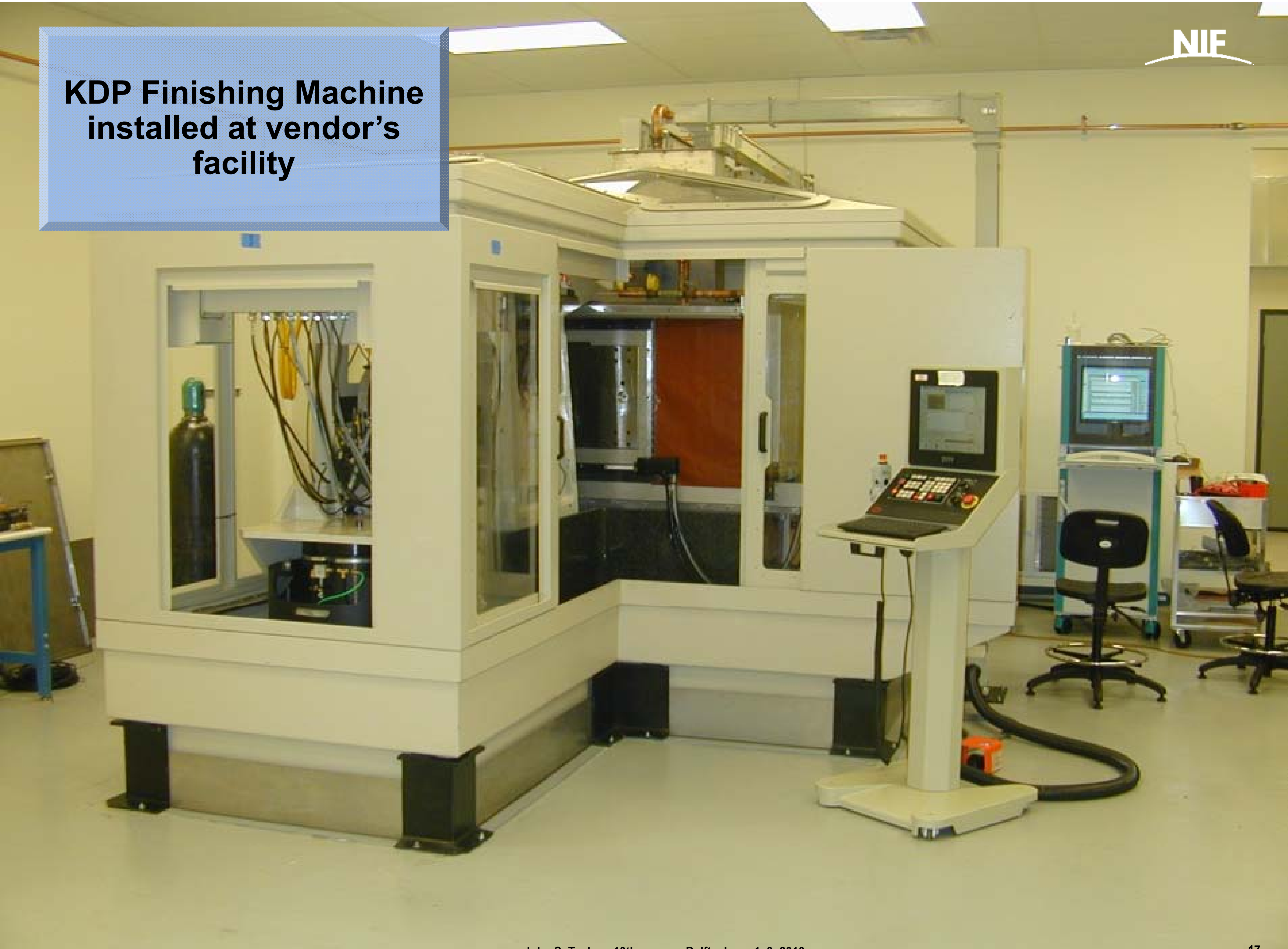
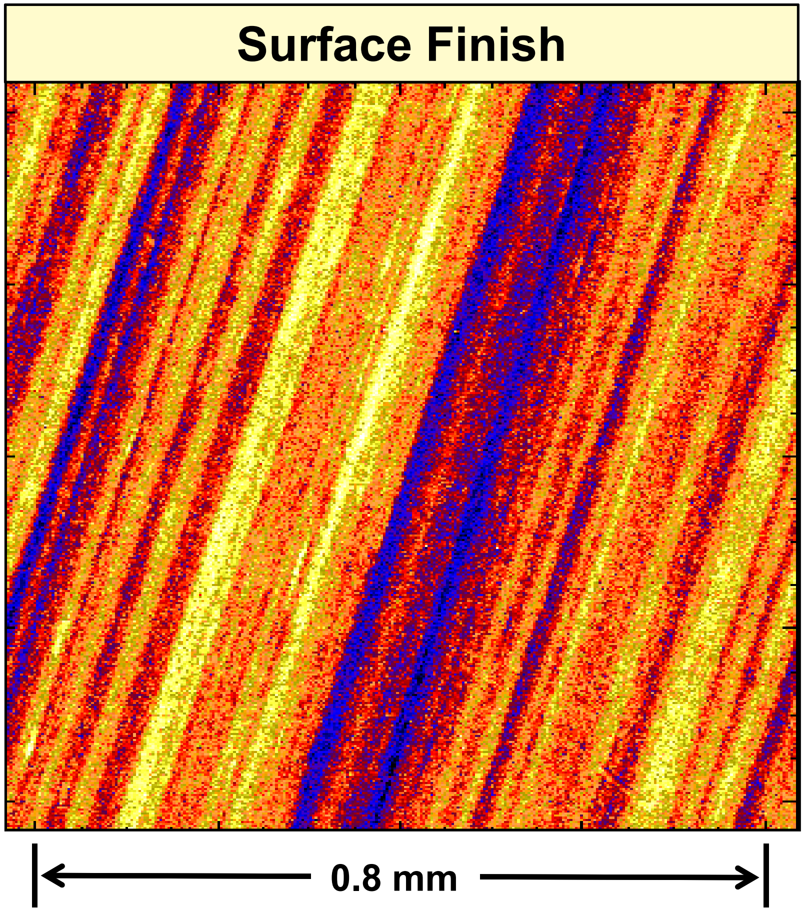
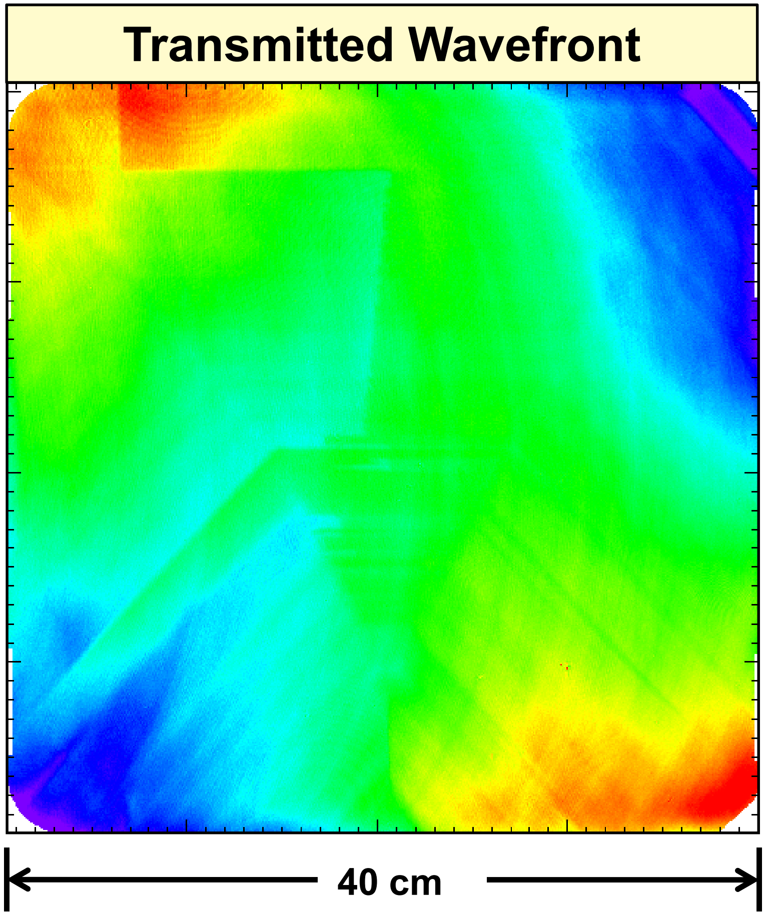


Figure and finish achieved by the final finishing machine meet NIF specifications



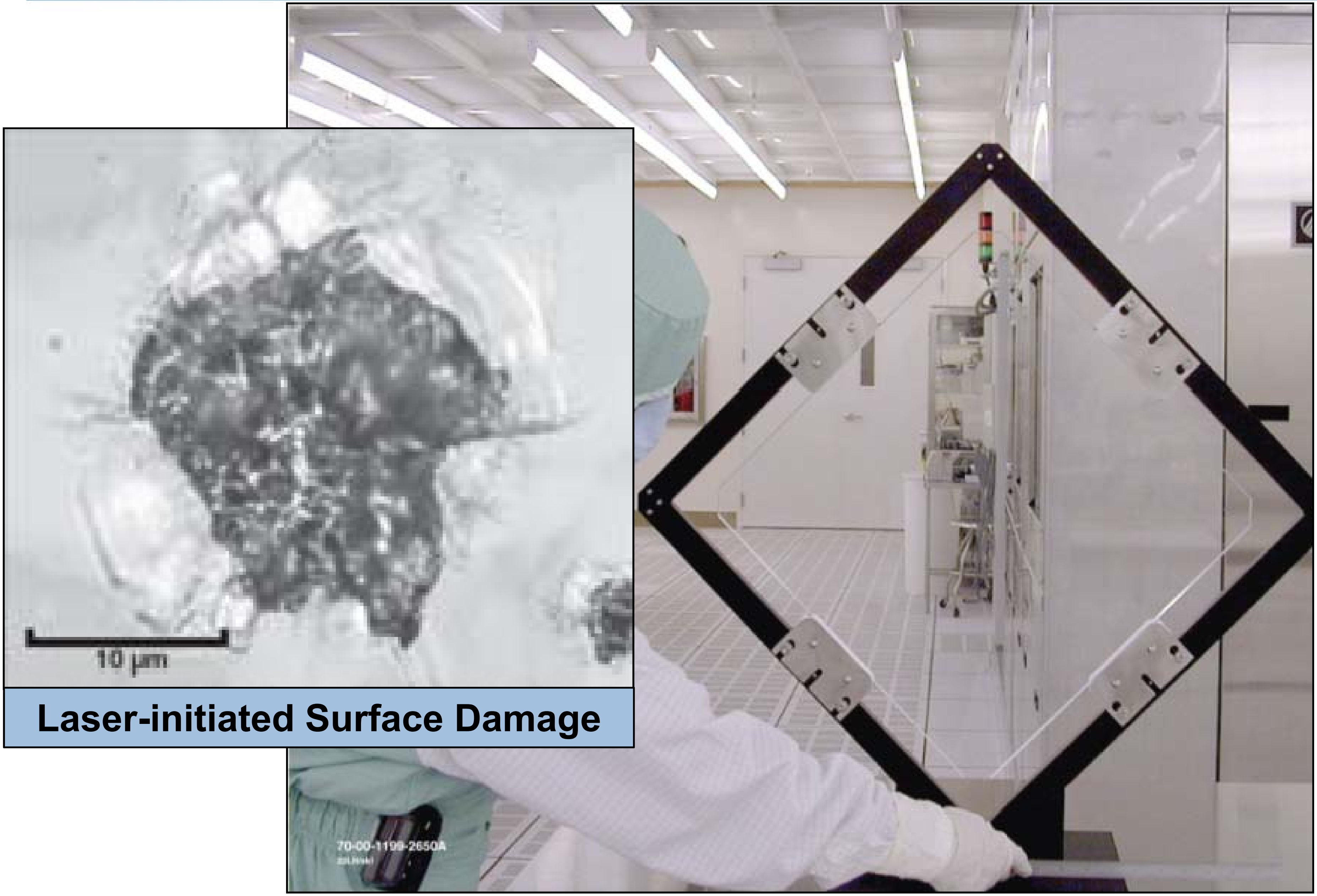
0.01 – 0.12 mm band 0.8 nm rms

0.12 – 2.5 mm band 1.0 nm rms



0.31 nm p-v waves @ 633 nm

KDP frequency conversion crystals are about 1 cm thick with a 40 cm square aperture



Laser-initiated Surface Damage

The KDP crystal is positioned above the milling spindle and machining stages

KDP Crystal

Milling at damage site

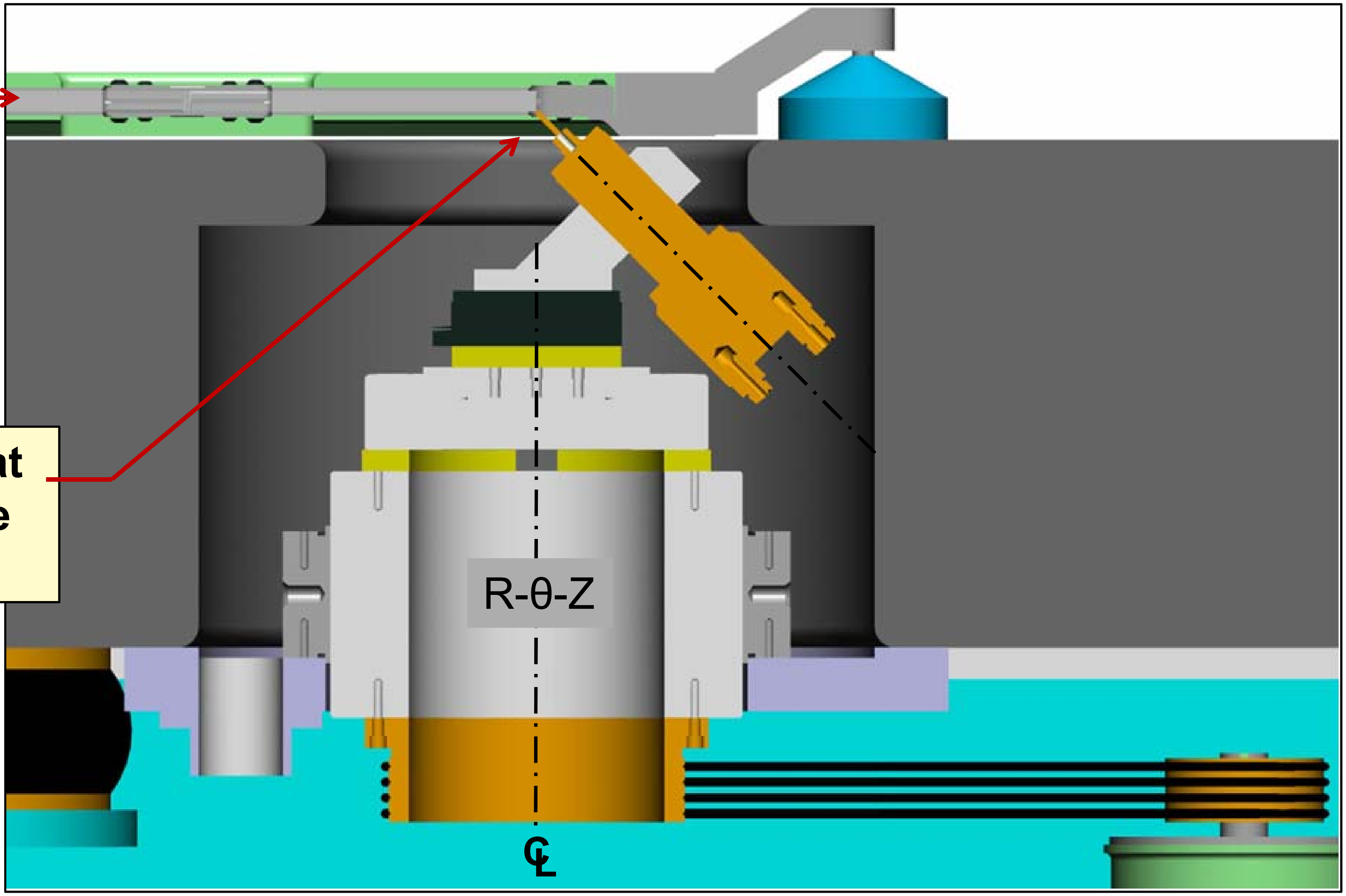
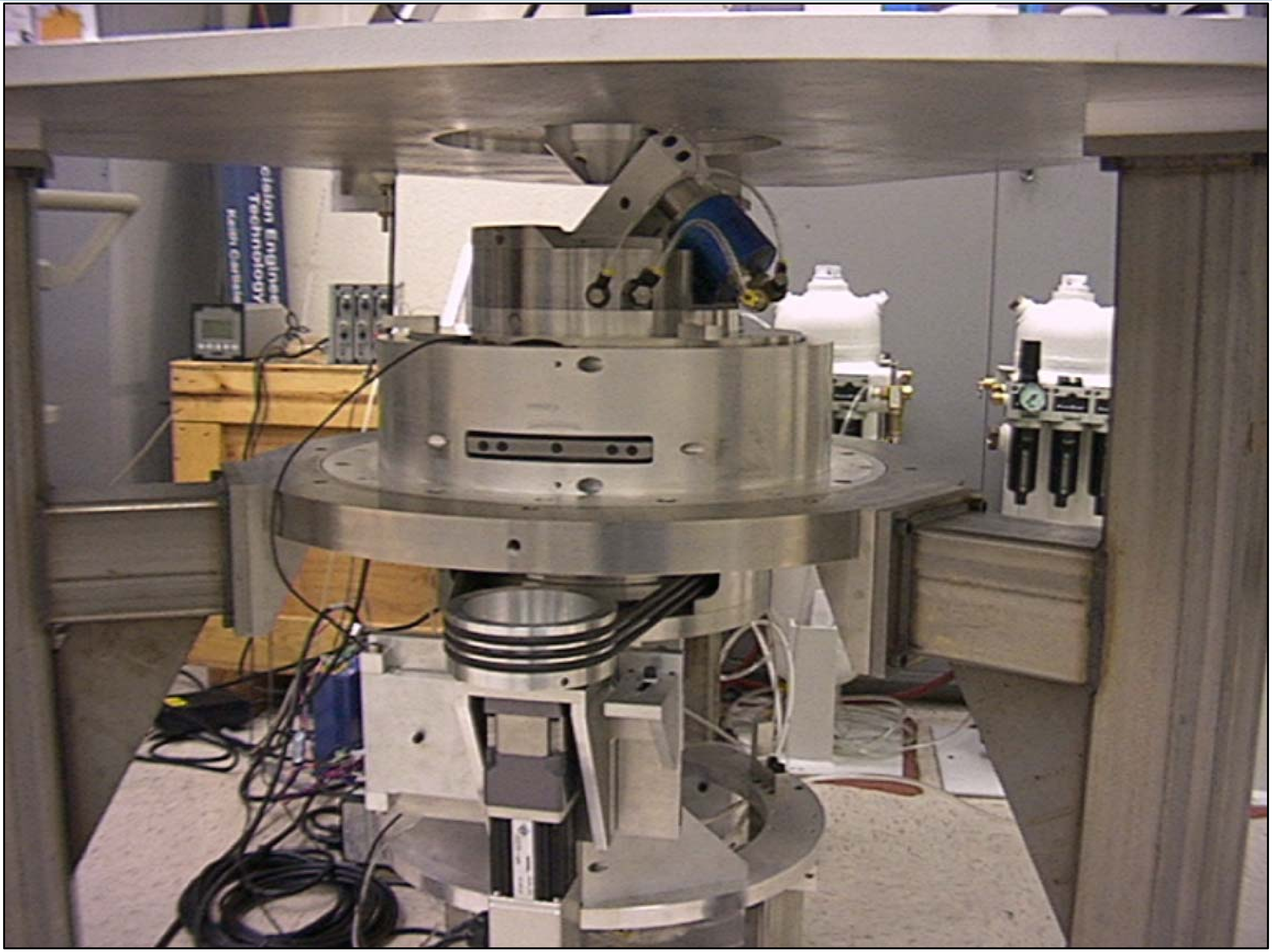


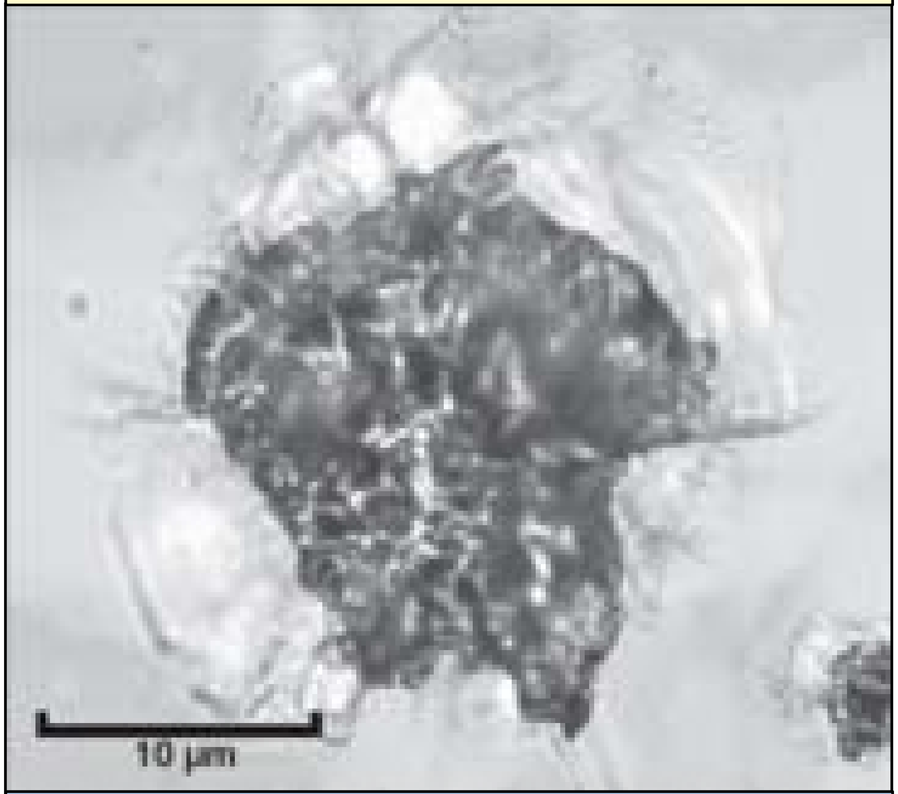
Photo of mitigation development system



Full-scale KDP mitigation tool

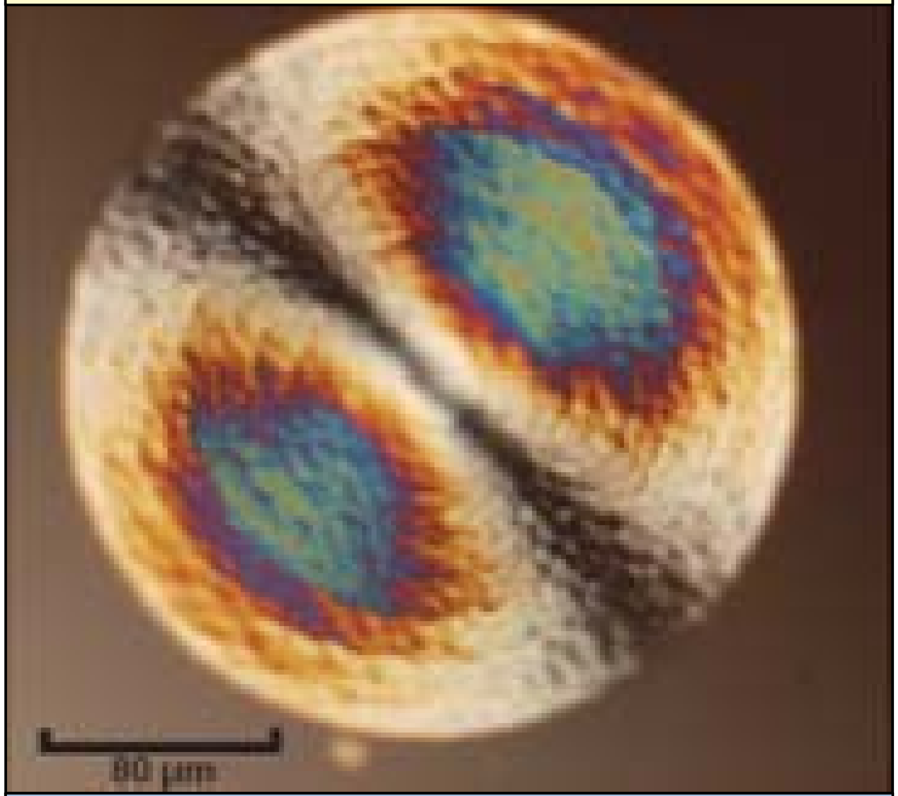
Example of KDP damage site mitigated by diamond milling operation

Before Mitigation



Laser-initiated Surface Damage

After Mitigation



Contoured Conical Surface

Mitigating damage on fused silica wedged focus lenses uses a CO_2 laser

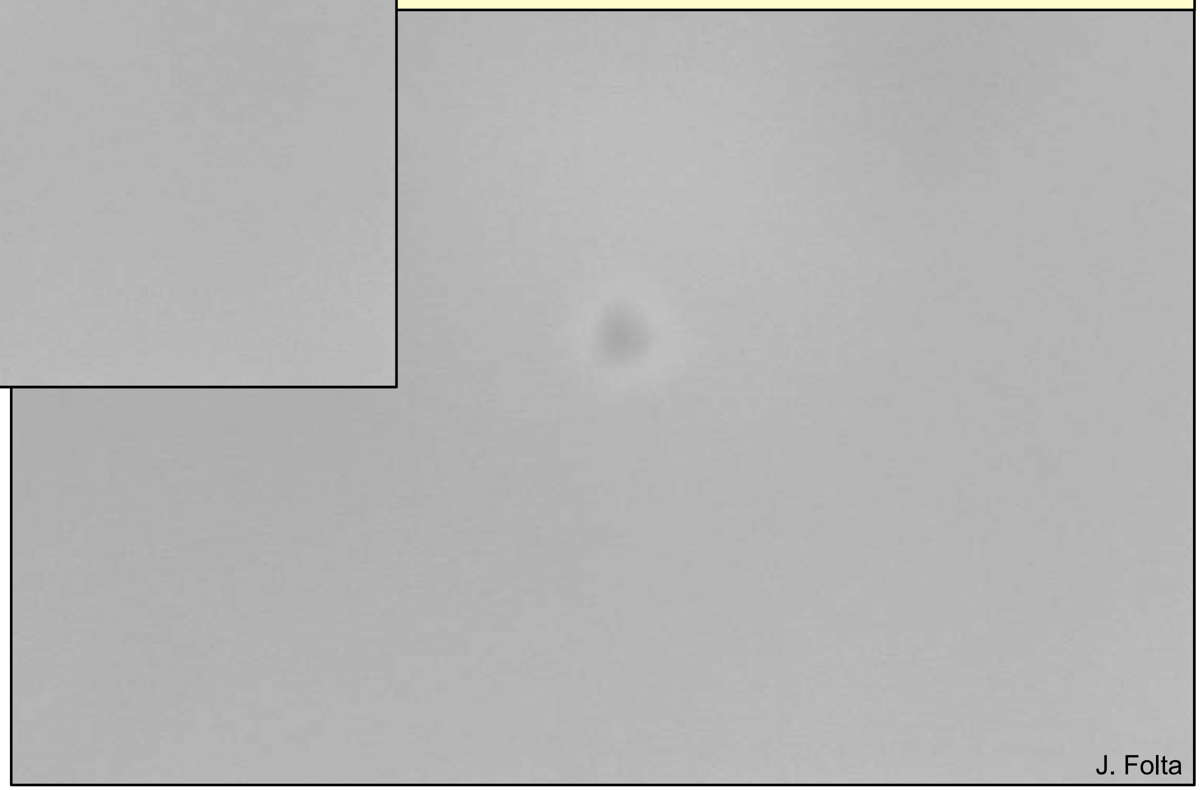
We have engineered machines and facilities to perform production mitigation on NIF optics

J. Folta

A collimated CO_2 laser beam is used to mitigate small damage sites on large optics instead of refinishing them

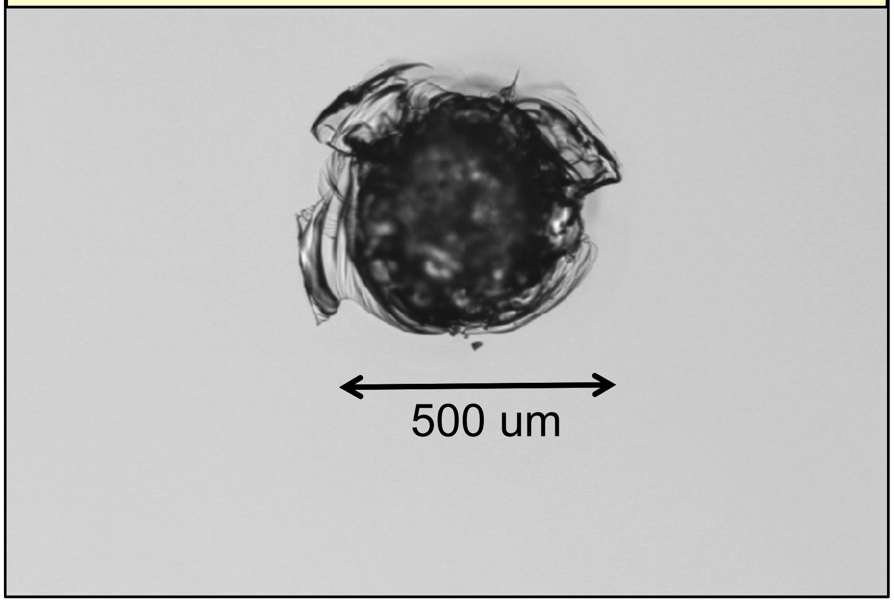
Before mitigation

After mitigation

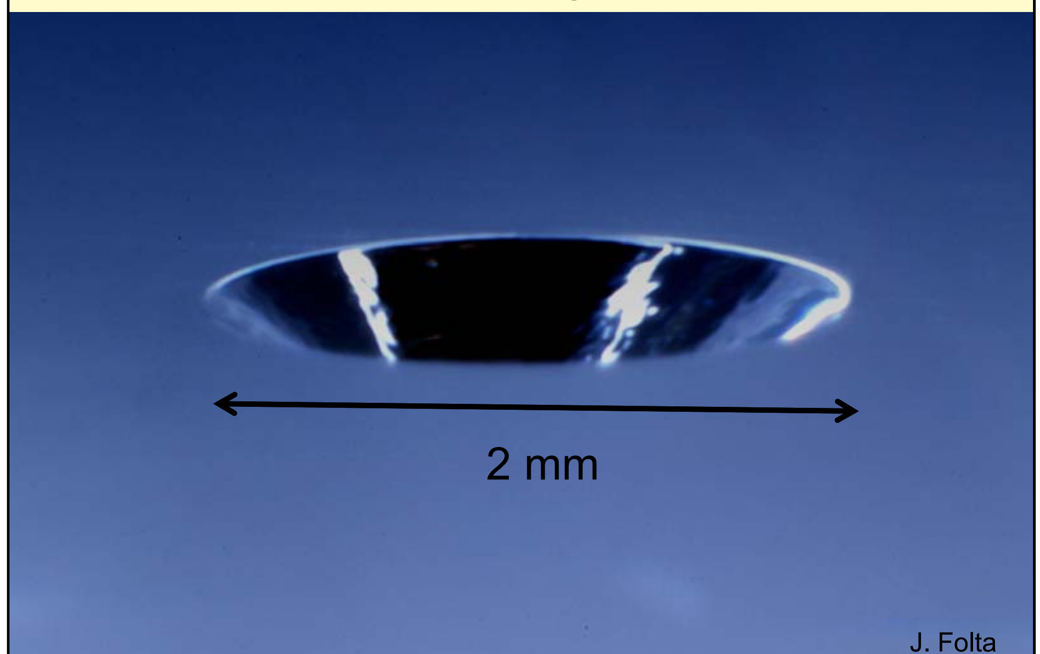


A focused CO_2 laser can be used to ablate conical pits to mitigate damage sites as large as 500 µm

Before mitigation



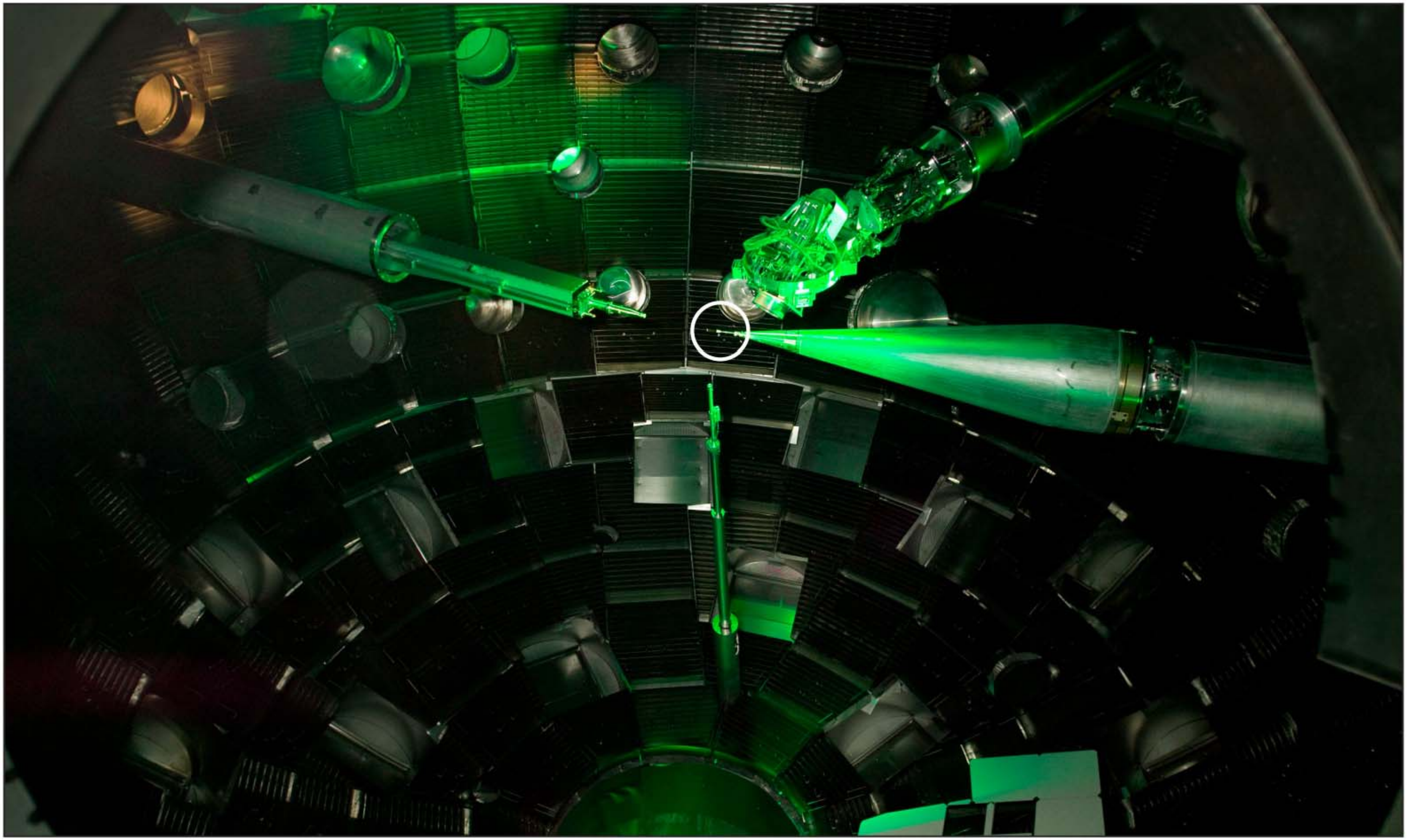
After mitigation



Rapid scanning of tightly-focused high-power CO_2 laser pulses to remove flaws

- Precise shape control
- Fairly wide process margin
- Scalable
- Damage robust

How do we go about aligning 192 laser beams, the target and diagnostics?



Target Alignment Sensor (TAS)

Target Alignment Sensor (TAS)

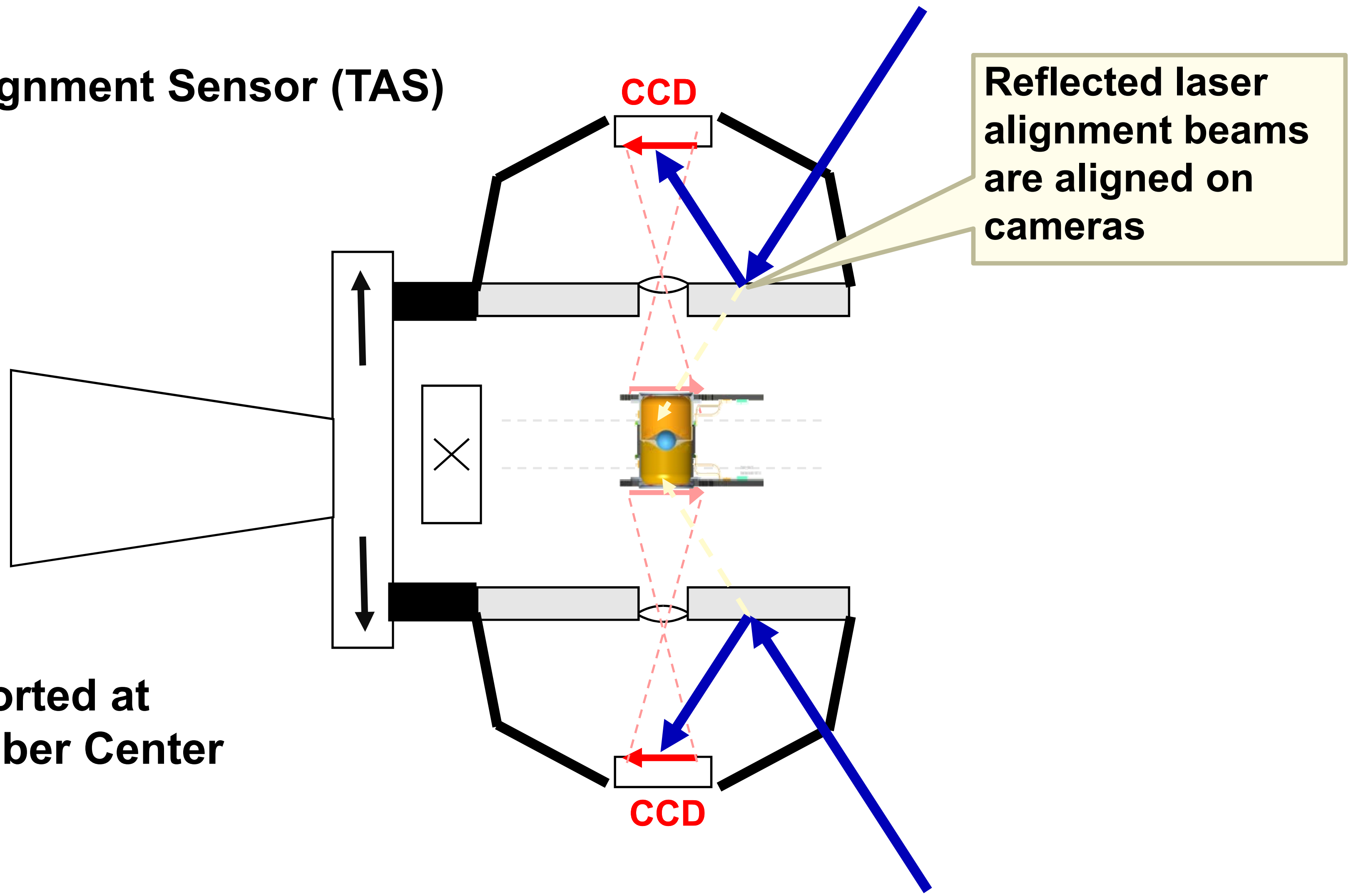
- Focus reference for each of 192 laser beams
- Identify location of datums on target
- Provide siting datum for diagnostic systems

TAS links the coordinates of the key elements of a NIF experiment

192 beams are aligned to the upper and lower cameras with an automated tool

Beams are aligned to a setpoint on the upper and lower CCDs

Target Alignment Sensor (TAS)

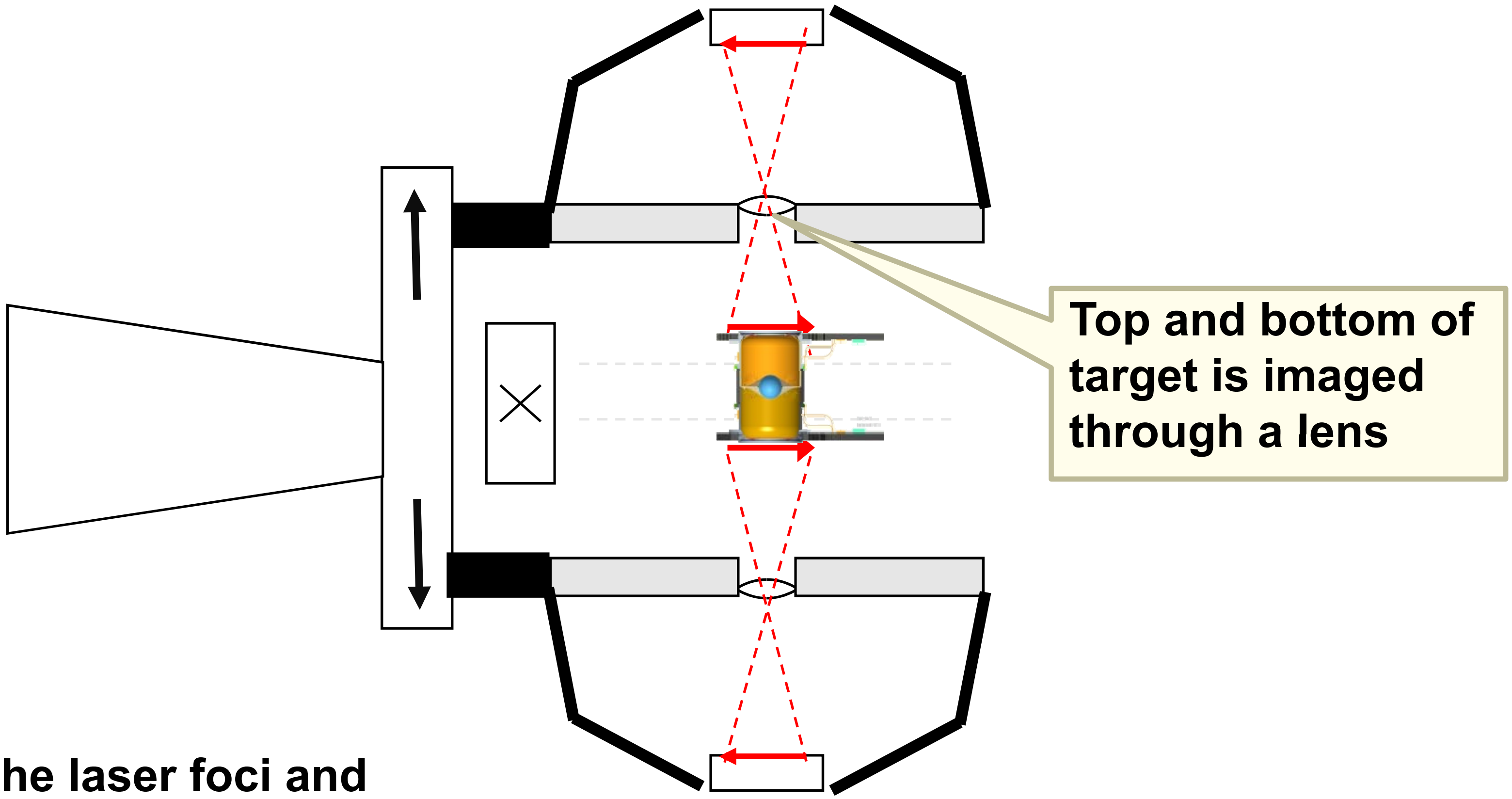


TAS is supported at Target Chamber Center

Target is aligned to a setpoint on the upper and lower CCD cameras

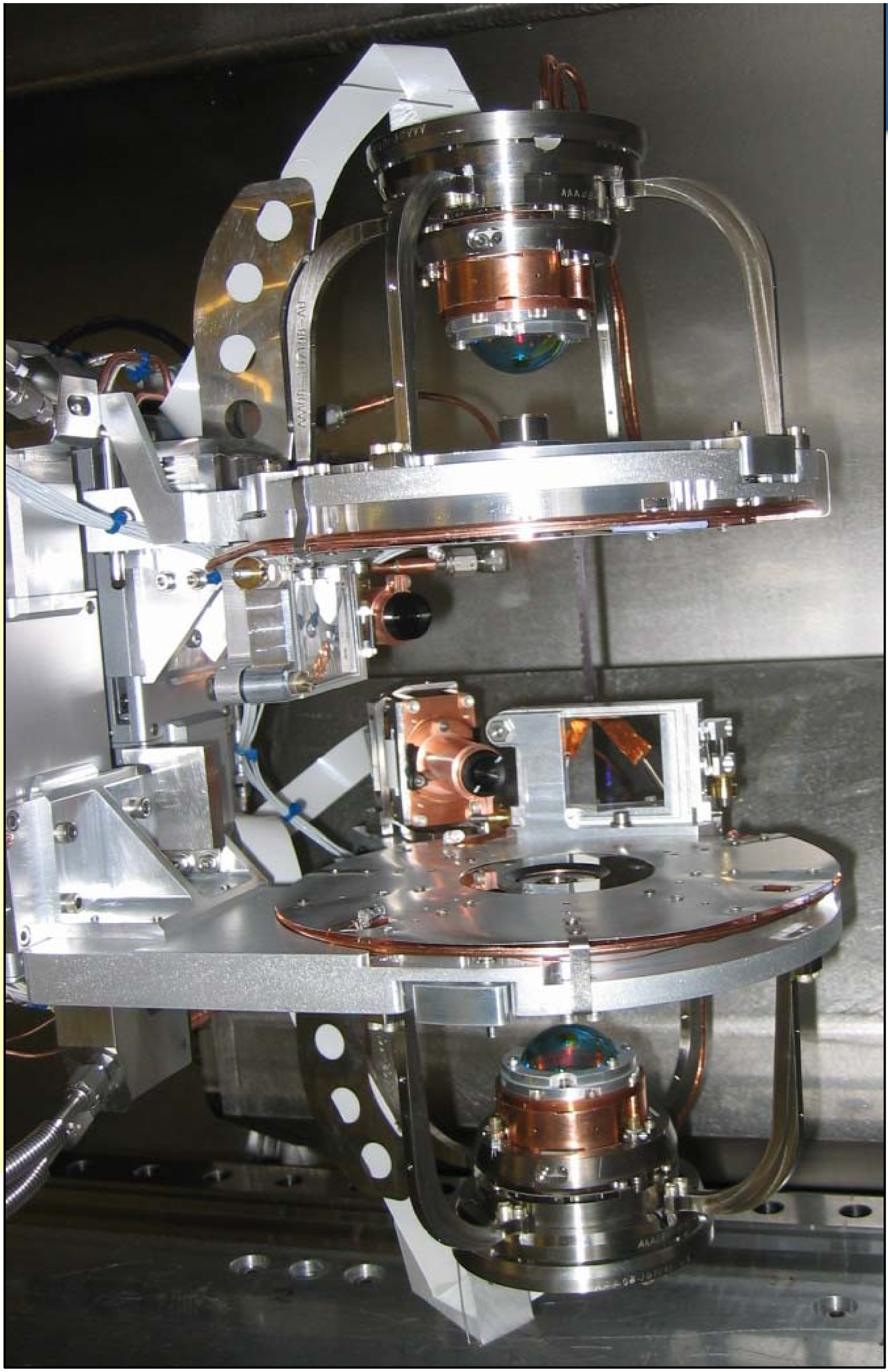
Platens open to focus and align target.

- Upper and lower cameras set four degrees of freedom
- Two side camera set target height



The key is that the laser foci and target are registered onto the same set of pixel coordinates

- **Target alignment sensor has been successfully deployed on NIF shots over one year**
  - **TAS is an intermediary between beams and targets**
  - **Calibrated accuracy of TAS is the central component of beam-to-target error budget**
  - **Requalification is expensive so stability is important**



Alignment performance

Target to NIF coordinate origin (1 mm zonal position req't):
300 µm deviation at last survey

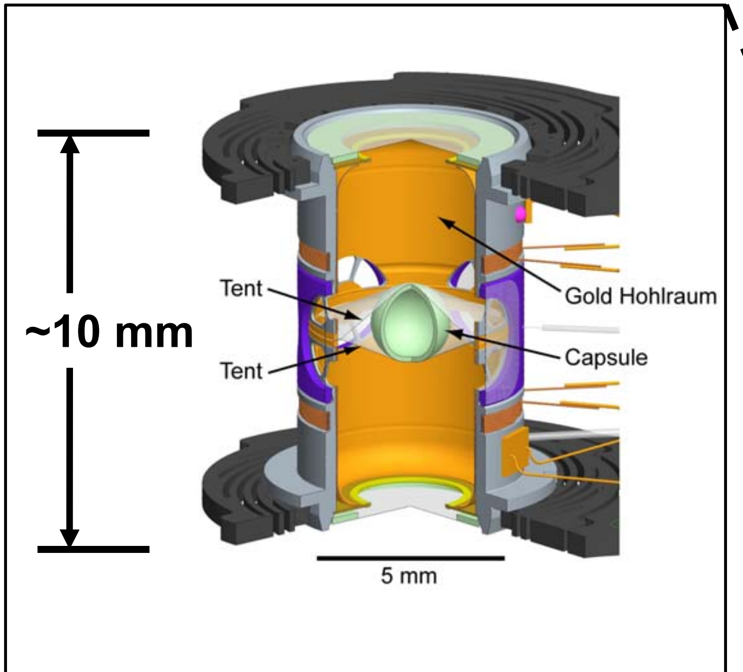
Target-to-chamber shot-to-shot position repeatability:
<100 µm

Position of 96 beam centroid at hohlraum:
<25 µm

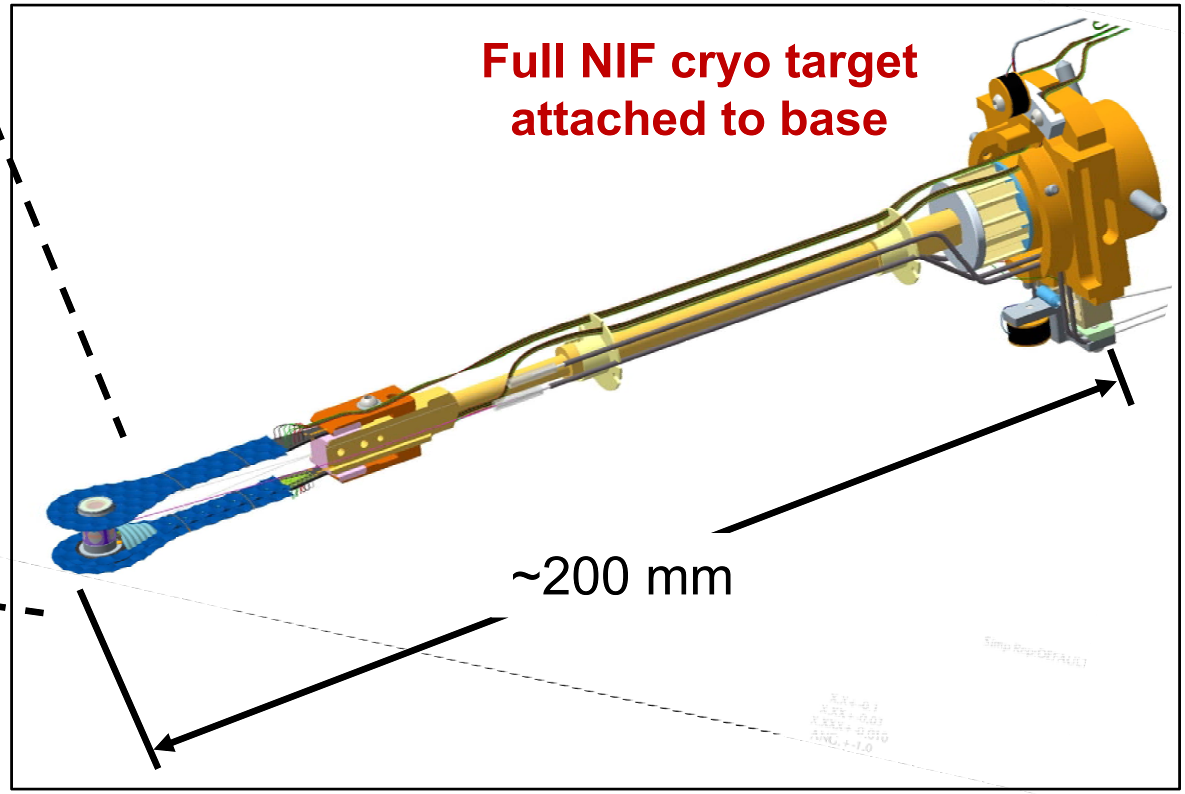
Beam pointing to target (1-σ of 96 beams):
64 µm rms

Diagnostic line of sight alignment (2-σ):
<500 µm

Fabricating and measuring targets is a fertile area for exercising precision engineering concepts



Capsule, Hohlraum Thermal-Mechanical Package



Component tolerances: 1-3 μm
Assembly tolerances: 1-20 μm
Bond gap tolerances: 0.25 μm

Dynamic Range: 1:10^4

Fabricating and measuring targets is a fertile area for exercising precision engineering concepts

Capsule, Hohlraum

~10 mm

<u>The dynamic range of 1:10^4 is challenging:</u>

Agility	required for new target types, target design modifications, and component variances
Human interface	for integrating motion control, force, visible-light microscopy, bonding
Production rate	greater than prototyping, less than HVM
Size	precludes use of many traditional tools (indicators, fasteners, etc)

Component tolerances: 1-3 μm
Assembly tolerances: 1-20 μm
Bond gap tolerances: ~0.25 μm

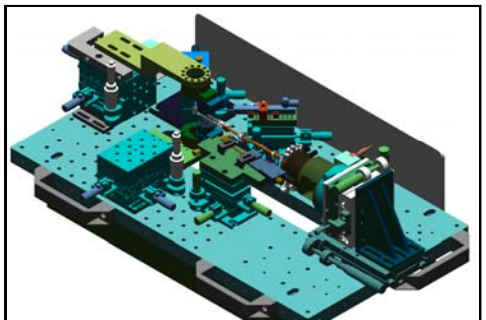
Dynamic Range: 1:10^4

Examples of Precision Engineering concepts in target fabrication

Precision Concept — Example

- **Rigorous tolerance analysis** — **Hohlraum length**
  - Monte Carlo analysis

- **Controlled degrees of freedom** — **Final Assembly Machine**
- **Precision with agility** — **Flex-FAM**



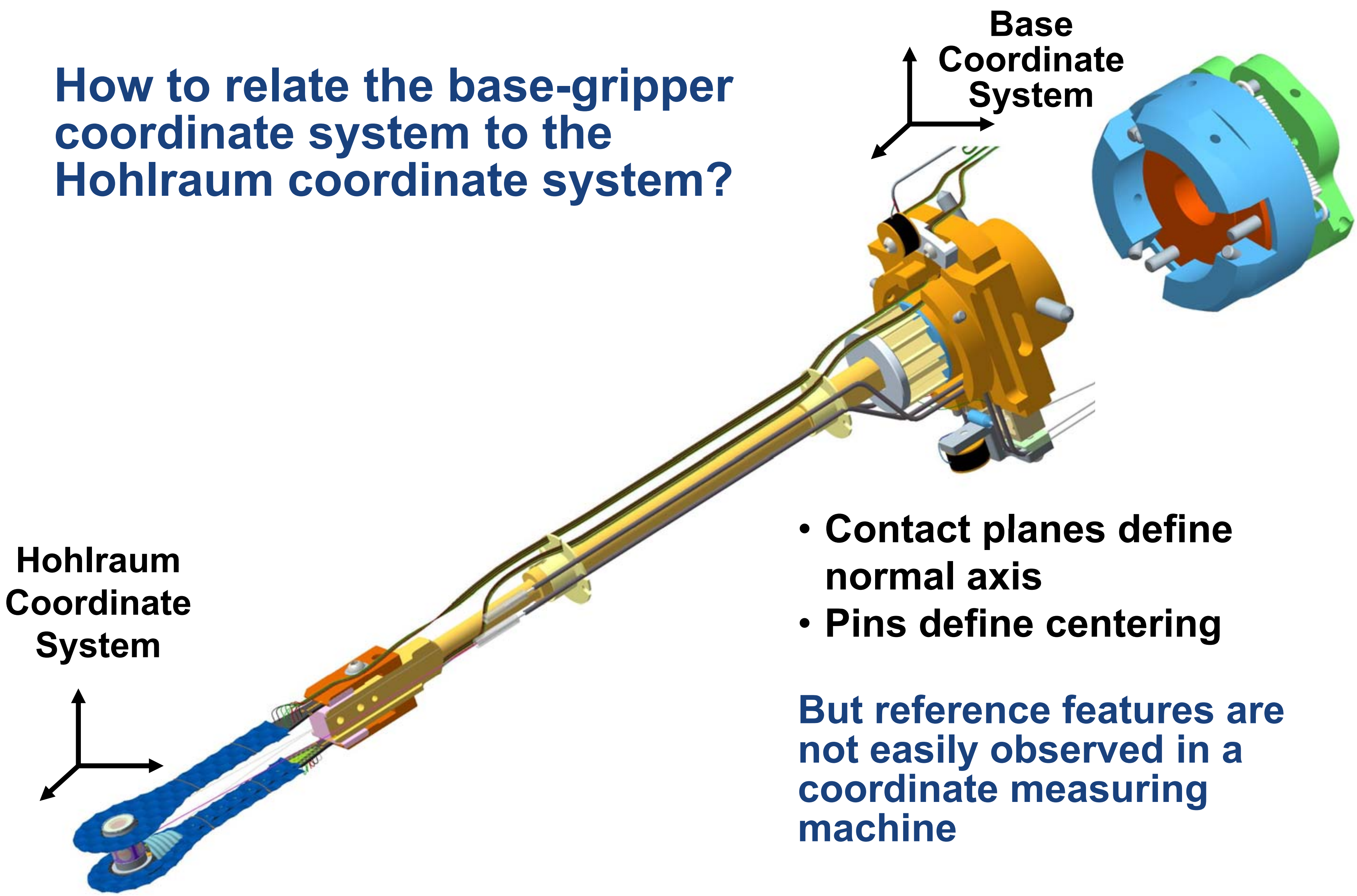
C. Castro

Rick Montesanti will discuss precision assembly in his talk

- **Design for measurability** — **Base metrology features**

Design for Measurability

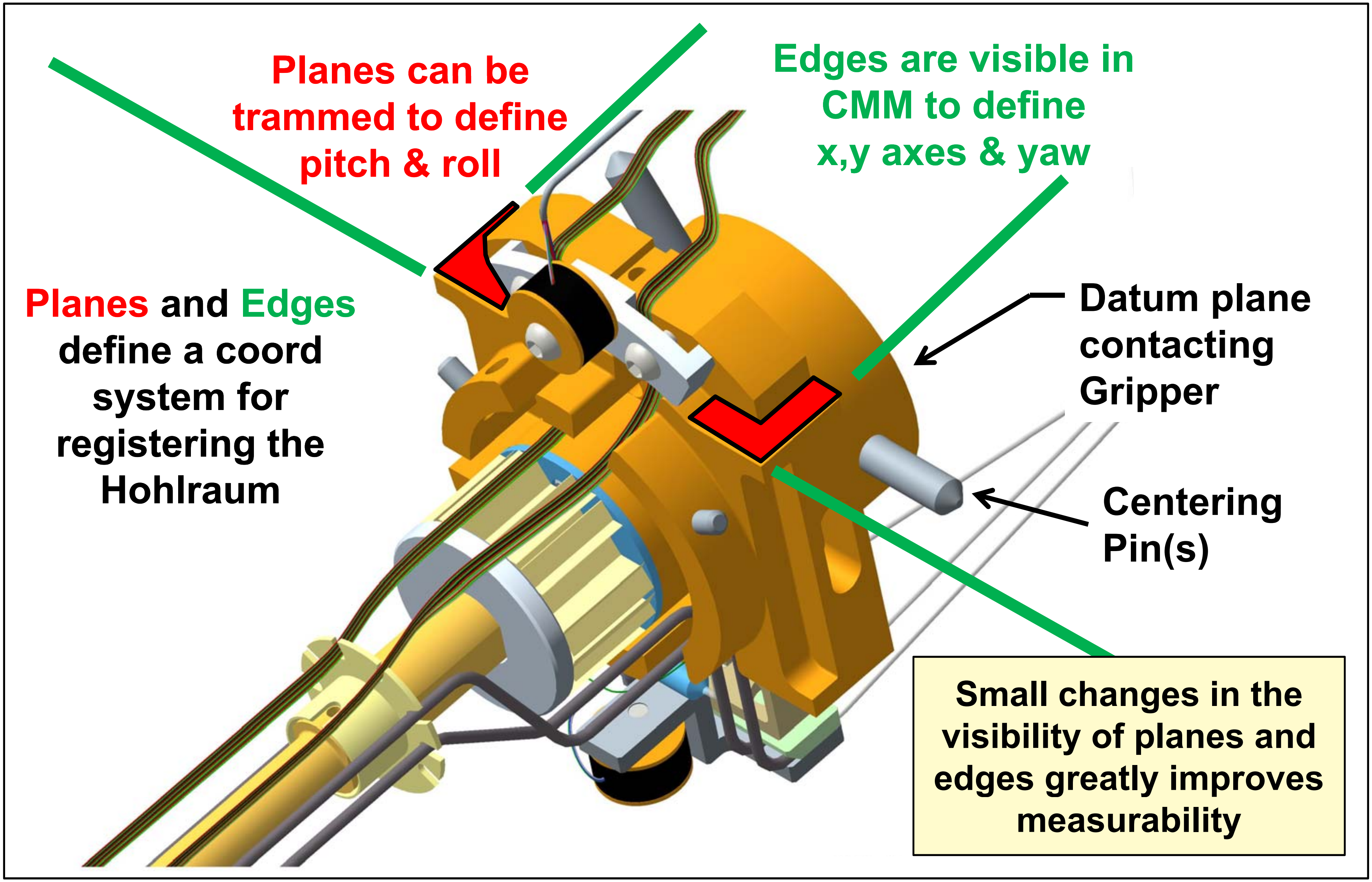
How to relate the base-gripper coordinate system to the Hohlraum coordinate system?



- Contact planes define normal axis
- Pins define centering

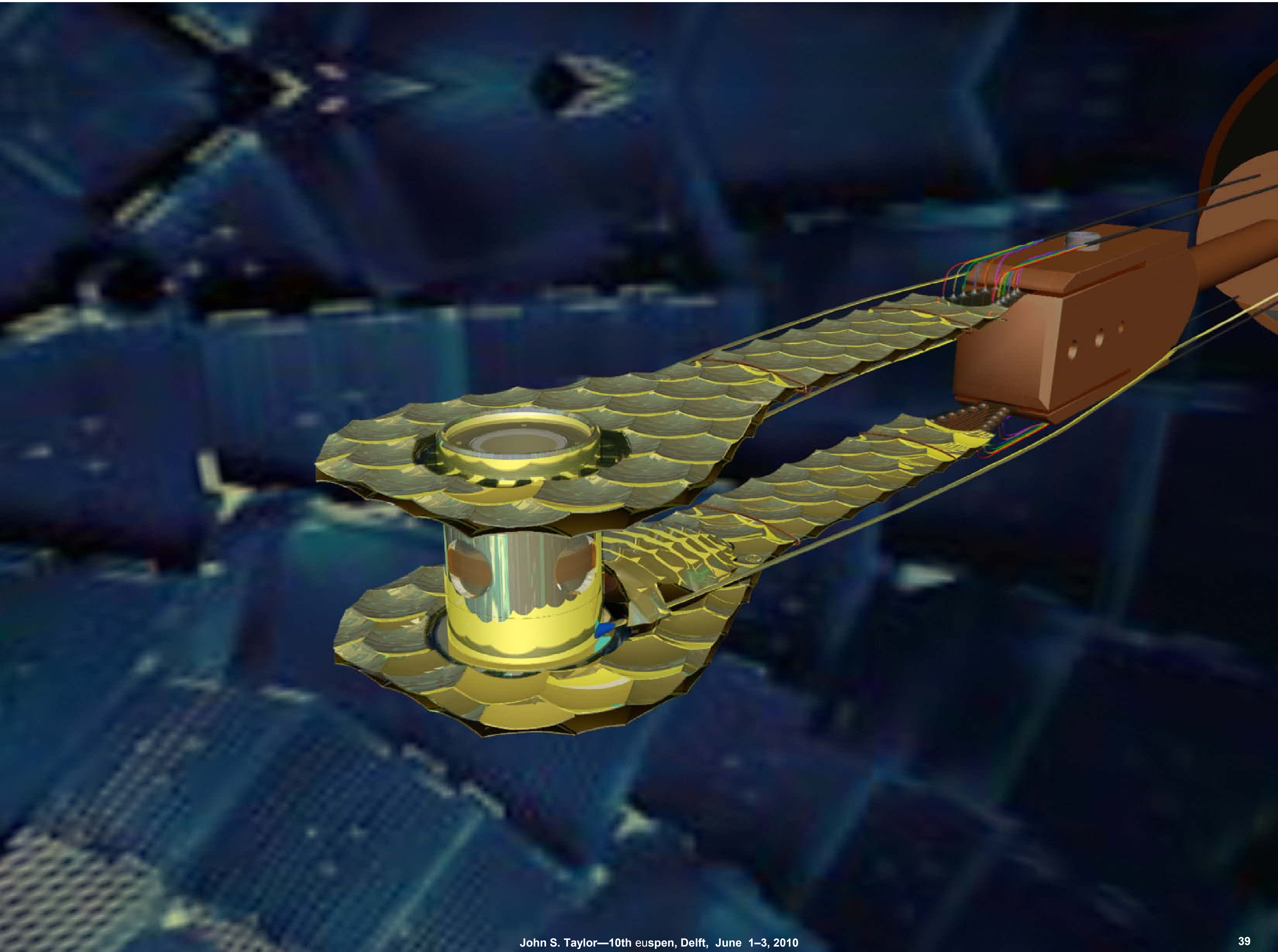
But reference features are not easily observed in a coordinate measuring machine

The design of metrology features onto the base enabled datums to be defined to register the Hohlraum

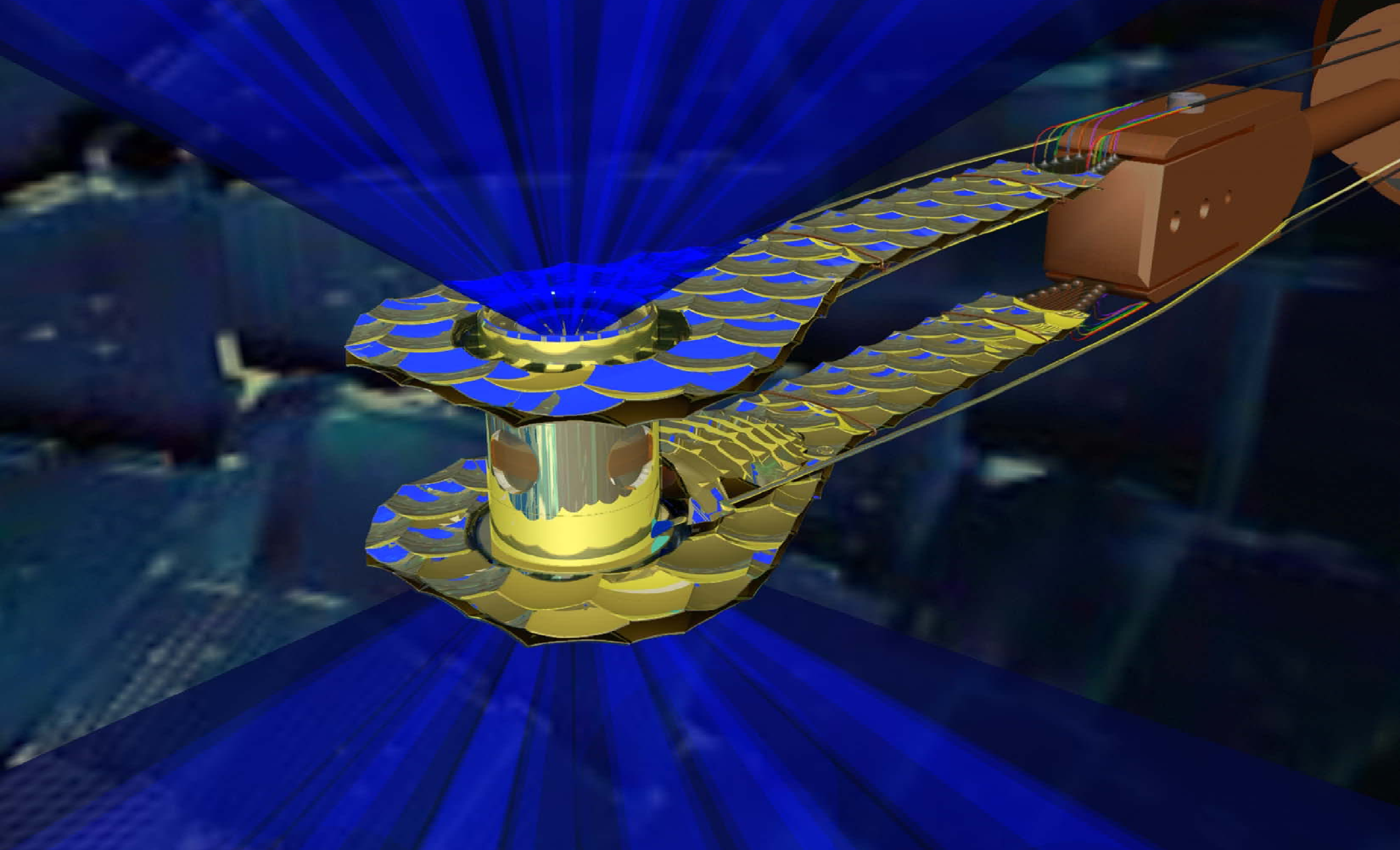


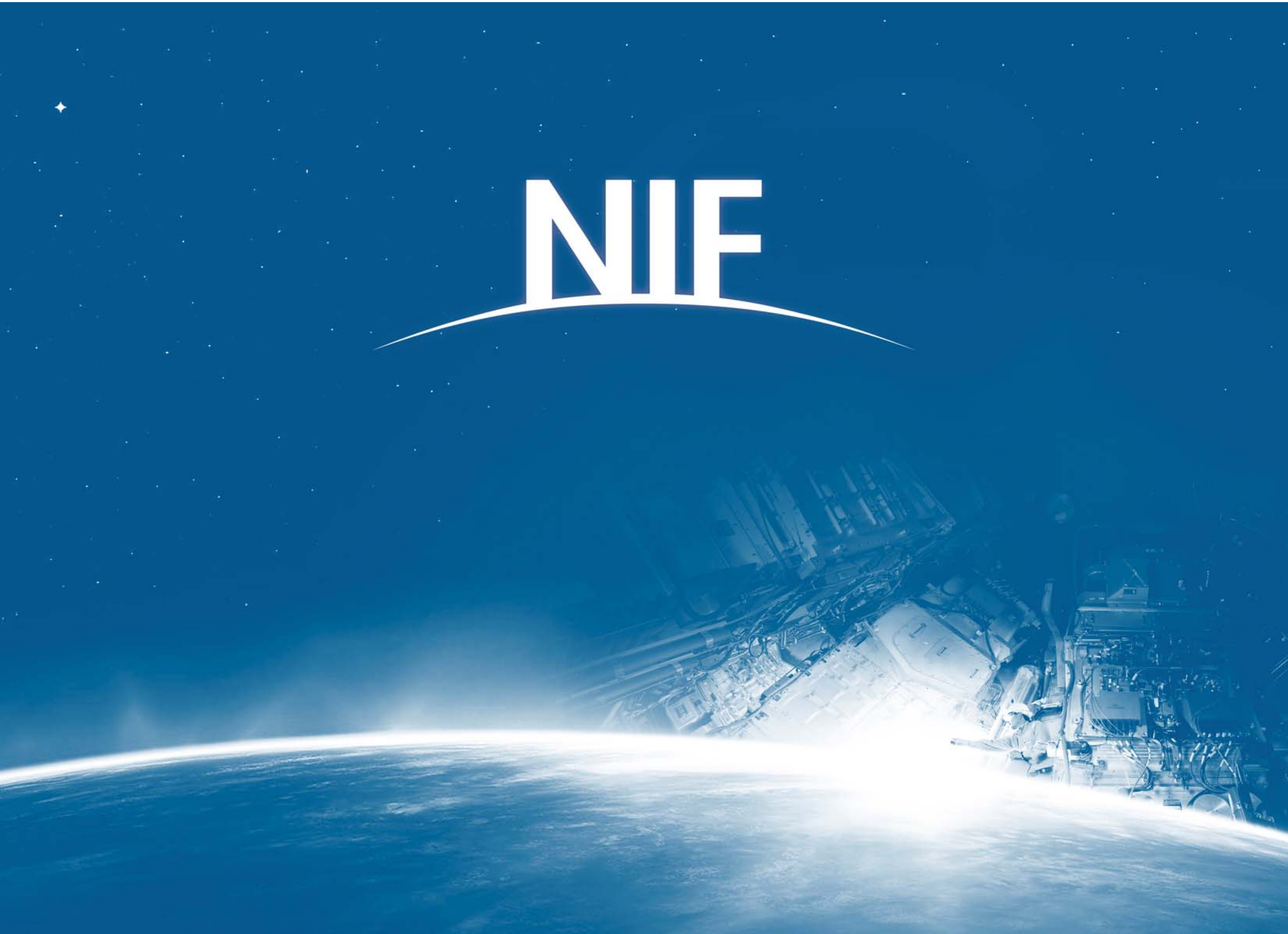
Small changes in the visibility of planes and edges greatly improves measurability

E. Alger, S. Edson



The long-sought goal of achieving fusion ignition and burn is close to realization




NIF